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Developing a Methodology for Evaluating Postural Control and Functional Ability in Children with Cerebral Palsy

Abigail Schoppa
Georgia Southern University

Developing a Methodology for Evaluating Postural Control and Functional Ability in Children with Cerebral Palsy

An Honors Thesis submitted in partial fulfillment of the requirements for Honors in *Health Sciences and Kinesiology*

By

Abby Schoppa

Under the mentorship of *Dr. Li Li*

ABSTRACT

Background: Cerebral Palsy (CP) is a non-progressive group of disorders that interferes with postural control and gross motor function (GMF). The purpose of this study was to develop a methodology to evaluate and link postural control and functional ability by identifying the best measures to use.

Methods: For this study, children between the ages of 12 and 22 who have CP and a Gross Motor Function Classification System level I to III were recruited. They performed a series of gross motor tests from the BOT-2 while standing on a force plate to record their center of pressure (COP) movement. Several measures from the COP data were identified and analyzed to identify which ones correlated best with the scores from the BOT-2 tests.

Results: The standard deviation of the quiet stance, a measure of static postural control, had the highest correlation with the functional scores. The COP range, a measure of dynamic postural control, had the second-best correlation with the functional scores.

Conclusion: This study successfully developed a methodology to link postural control and functional ability by identifying the quiet stance SD and the COP range as the best measures for future research.

Keywords: Cerebral Palsy, postural control, functional ability, gross motor function, BOT-2

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Introduction

Cerebral Palsy (CP) is a non-progressive group of disorders that interfere with the development of movement and posture. CP is the most common motor disorder in children. It is often acquired early in life when a child endures an event causing lesions or abnormalities in the brain that interfere with development. Motor impairment from CP is "often accompanied by disturbances of sensation, perception, cognition… and by secondary musculoskeletal problems" (Pakula et al., 2009, pp. 426–427). These deficits lead to abnormal development of postural control, which is essential to mastering more complex tasks that involve greater gross motor function (GMF), such as catching, running, skipping, and jumping (Chen & Woollacott, 2007). Completing complex tasks is essential for participation in activities of daily living (ADLs). The Gross Motor Function Classification System (GMFCS) evaluates GMF in children with CP, classifying them from levels one to five (Pavao et al., 2014). Health professionals evaluate the motor skill levels of children, with a focus on their abilities on a normal basis, rather than their limitations. This helps create a clearer picture of the child's functional abilities and the aids they may need in the future ("Gross Motor Function"). People at levels I to III can ambulate unassisted without using a wheelchair and can maintain postural control for a period without any aids. People at level I have the greatest ability, ambulating with no limitations, while people at level III may need some mobility aids. People at levels IV and V likely need a wheelchair for mobility and have difficulty independently standing and maintaining postural control (Jansheski, 2023). Understanding the relationship between GMF, postural control, and participation in ADLs is important to understand why improving postural control is crucial for motor improvement.

GMF, postural control, and performance of ADLs are interdependent. Higher levels of GMF allow greater control over body movement and maintaining posture. This allows increased independence in life and more opportunities to participate in ADLs that lead to greater fulfillment (Tarfa et al., 2021). Pashmdarfard and Amini (2017) looked at the relationship between GMF and ADLs based on parent reports of children with CP using GMFCS levels of the child and the Children Participation Assessment Scale- Parent version (CPAS-P). The study identified a moderate to good relationship between participation in ADLs and GMFCS levels. Children with a lower GMFCS level participated in significantly more ADLs than children with higher classification levels and, therefore, have greater potential to live a more independent and fulfilled life (Pashmdarfard & Amini, 2017). Additionally, a significant positive correlation was reported between trunk control, GMF, and ADLs in a study that looked at the influence of variables such as spasticity, trunk control, upper limb function, and lower limb function on GMF and the ability to perform ADLs further supports the relationship between GMF and ADLs- having well developed voluntary control over the trunk results in improved postural control and ability to complete ADL's (Tarfa et al., 2021). Postural control uses the integration of sensory information from the visual, vestibular, and somatosensory systems to work against gravity to maintain an upright posture with tonic muscle contractions and maintain equilibrium and body segment alignment during perturbations (Ivaneko & Gurfinkel, 2018). Parker (2018) defines balance (used synonymously with postural control) as the maintenance of posture through control of body alignment (para. 2). Having adequate postural control greatly increases a person's level of mobility. With increased trunk control and GMF, people are able to better perform and participate in ADLs due to increased postural control and mobility. (Tarfa et al., 2021). Due to the deficits in motor control from CP, these areas are significantly impacted and underdeveloped, making participation much more difficult.

CP negativity impacts muscular control and makes maintaining posture and moving around difficult. These deficits negatively impact balance and GMF. Pavao et al. (2014) reported significant differences in balance measures between children with CP with GMFCS classification levels I, II, or III using the Pediatric Balance Scale (PBS), a modified version of the Berg Balance Scale made specifically for children. This relationship illustrates that as balance and postural control ability increase, GMFCS levels decrease. Another study reported a similar correlation between gross motor function (GMF) and balance in children with CP using the Lower Extremity and Trunk sections on the Motor Age Test, two clinical balance tests, and the Smart Balance Master system (Liao & Hwang, 2003). The relationships and correlations identified between GMF and balance ability support the idea that as balance ability increases, so does GMF. These overarching relationships further demonstrate how intertwined balance and postural control, GMF, and ADLs are. This is important to note because it points toward the idea that improving postural control could be a way to improve ADL participation. Quantifying both static and dynamic postural control differences between typically developing children (TDC) and children with CP is beneficial to improving function in daily activities.

Many studies that research postural control in people with CP focus on static postural control and use force plates to measure center of pressure (COP) movement, a measure of postural control. These studies have identified differences in postural control, indicating the use of force plates as a good measure. Rose et al. (2002) looked at standing balance in ambulatory children, ages five to 18, with diplegic CP to determine if it was abnormal compared to TDC. The participants stood on force plates with bare feet while measurements, including COP, were taken. The results demonstrated that postural control did not improve with age in the CP group, while it did improve with the TDC (Rose et al., 2002). The lack of postural control development over time in people with CP is likely due to the deficit CP causes in motor control. Additionally, a study measured standing and sitting balance using similar procedures and compared COP data to the PBS's static and dynamic balance measurements (Shim et al., 2022). Standing trials are a typical measurement of balance while sitting balance is more indicative of trunk postural control. The COP data from these trials strongly correlated with the static PBS scores, likely because the participants stood and sat still (Shim et al., 2022). A new direction to take these studies would be to look closer at measures of dynamic postural control because they account for resistance to perturbations reported when participating in ADLs, making them more authentic and applicable to real-life situations.

Few studies have examined differences in dynamic postural control in the CP population using resistance to perturbations. In a few studies, researchers used force plates to measure changes in COP and other variables in response to a perturbation to identify differences in postural control strategies used by CP and TD participants. When encountering a perturbation, people with CP have slower reaction times and lower-intensity muscle contractions during anticipatory postural adjustments (APAs) than TDC (Shiratori et al., 2016). APAs are used to prepare for and counteract the effects of an anticipated perturbation. Preparing and adjusting for perturbations allows a person to have better postural control after encountering said perturbation. Shiratori et al. (2016) measured muscle contractions and COP data when participants caught a predictable falling mass. Muscle contraction data illustrated that co-contraction of muscles was used in the CP groups but not in the TD groups. Additionally, there were smaller anticipatory changes in COP, indicating less control of COP. All of these observations are indicative of people with CP having a decreased ability to react to and withstand perturbations. This study also uses predictable perturbation, which is less authentic to the unpredictable real world. Another study created unexpected perturbations using a movable force plate at varying speeds while participants maintained standing postural control, which better mimics real-life scenarios and creates reactionary responses. Like the previous study, Chen and Woollacott (2007) reported that people with CP had slower reaction times and decreased ability to withstand the perturbations (indicated by greater velocities). One additional observation was the overwhelming use of a hip-based strategy to maintain postural control in the CP group compared to an ankle-based strategy used in the TDC group. This demonstrates poor coordination between joints in the CP groups and greater advancement in strategy for the TDC group. These studies demonstrate that in the presence of perturbation people with CP have slower reaction times and use different postural control strategies than TD people. These differences are likely due to the physical limitations of CP. It would be useful to expand on dynamic postural control research by quantifying the variability of postural control in the presence of perturbations and its relationship with gross motor function.

One example of a reactionary perturbation that could be studied is catching a ball with your hands and resisting the force to maintain postural control. The knowledge and development of this skill generally happens over time with practice. However, due to the constraints of CP, catching is an underdeveloped skill in this population. When assessing the development of catching, there are three areas of focus: arm action, hand action, and body action. As the skill develops, greater movement and coordination are seen in each area, which helps complete the catch with greater accuracy (Haywood & Getchell, 2002). There is no difference between TD and CP children in the declarative knowledge of the catching skill, indicating that both groups have a similar understanding and knowledge of catching (Kourtessis & Reid, 1997). However, the two groups had large developmental differences when performing the skill. As the TDC increased in age, the performance of catching a ball increased, but in the CP group, there was no improvement in skill over time. This difference could result from the physical limitations of CP and lack of practice due to limited accessibility to opportunities where they could participate in activities (Kourtessis & Reid, 1997). The impaired motor performance of people with CP during a catching task results in greater perturbations upon the catch, due to decreased ability to prepare for and absorb the force of the object being caught. These deficits impede the ability of people with CP to maintain postural control during a catching task. This concept can be applied to most activities involving gross motor coordination and interactions with unexpected stimuli. Looking further into the relationship between postural control during perturbations and GMF will provide insight into the impact on real-life movement and participation in ADLs.

Having greater muscle control allows for more refined coordination of movement. This would present more consistent movement patterns in TDC and children with greater postural control. In contrast, children with less postural control, such as children with CP who have higher GMFCS classifications, would present with more inconsistent movement patterns due to less developed muscular/postural control. When looking at testing data, these differences should present themselves in differences of variability. Variability measures how spread out or consistent a set of data is. That is, data sets with similar data points will have low variability, while data sets with greater differences between data points will have high variability. A few different measures of variability that could be looked at when examining postural control are standard deviation (SD) and the range of COP movement. SD would be good to use when evaluating COP because it has greater respect for the units of measurement (Yeo & Cacciatore, 2017). The range of the COP movement would provide insight into how much the COP moved overall. Lower variability translates to more consistent results when applying variability to testing data. This would look like small standard deviations and smaller total COP movement. For this reason, children with a greater ability to maintain postural control should have lower variability than children with decreased postural control due to more consistent posture maintenance. Higher variability would indicate a lack of postural and motor control.

Quantifying different measures of variability in postural control when encountering perturbations, such as catching a ball, in children with CP will allow the best measures to be identified and used in developing a methodology to link postural control during perturbation with GMF. This research will provide a new direction to take dynamic postural control research into that is more applicable to real-life scenarios. Additionally, it will provide a bridge to understanding how these interdependent factors impact ADLs and the overall quality of life for children with CP. This will help future clinicians, adaptive sports professionals, coaches, educators, and families evaluate GMF and postural control more easily and understand their implications in life.

Methods

Purpose

This study's purpose was to develop a methodology for linking postural stability and functional performance among children with CP.

Design

This study analyzed COP data from force plates during four different functional tests to identify the best measures of postural stability and develop a methodology for linking postural control and functional ability in children with CP. Data was collected from two participants throughout three testing sessions.

Participants

The first participant in the study was a 15-year-old male. He completed two test sessions. The second participant in the study was a 17-year-old female who completed one test session. Participants who have CP were recruited for this study using the following inclusion criteria: (1) are between the ages of 12 and 22 years old, (2) are classified as a GMFCS level I to III, (3) are cleared by a medical professional for participation in physical activity, and (4) have the ability to perform activities of daily living (ADLs) using one upper extremity. Participants were excluded from the study if they met the following exclusion criteria: GMFCS levels IV or V. These children most likely cannot maintain standing postural control for 10 seconds unassisted, limiting the ability to record accurate baseline data.

Instrumentation

Center of pressure (COP) data was collected from participants using a 40 cm x 60 cm AMTI OR6 Series Force Platform (AMTI, Watertown, MA, USA) with a 1000 Hz sampling rate.

The COP was recorded in millimeters (mm). The time and y-coordinates were extracted and analyzed to determine COP changes in the mediolateral direction.

The procedures from the Upper Limb Coordination subsection of a modified version of Bruininks-Oseretsky Test of Motor Proficiency Second Edition, the Modified BOT-2, were followed to administer four different dropping and catching tests with a ball. The BOT-2 is a valid and reliable measure of motor skills, such as catching and throwing (Bruininks & Bruininks, 2005). The functional results, either catching or not catching the ball, were recorded for each trial and a functional ability score was given out of five for each test.

Procedures

Participants completed four different tests during each testing session: (1) dropping and catching a ball with both hands, (2) catching a tossed ball with both hands, (3) dropping and catching a ball with one hand, and (4) catching a tossed ball with one hand. The participants had one practice attempt and five recorded test trials for each test. For each test, the participants had one practice attempt, followed by five recorded test trials. The examiner gave participants the instructions and a demonstration for each test before it began. All tests were measured on the force plate. The functional results will be recorded on a data sheet for each trial during the tests.

For the first test, dropping and catching a ball with both hands, participants were instructed to hold a tennis ball with both hands and extend their arms in front of their body while standing barefoot on the force plate. Once in position, participants dropped the ball and caught it with both hands after it bounced on the ground once. One drop-and-catch attempt constituted one trial. The examiner demonstrated this movement before starting the test. After the demonstration, participants conducted one practice attempt to ensure understanding of the test. After the practice attempt, the test began. Each of the five trials started with a ten-second quiet stance to record baseline data. The participants were instructed to stand as still as possible in the middle of the force plate, in their normal stance with their hand by their side, while looking straight ahead at a predetermined mark on the opposing wall. Immediately following the quiet stance, the participants completed one trial of dropping and catching the ball. After attempting or completing the catch, the participants completed another 10-second quiet stance following the previously stated procedure. The trials did not have to be consecutive. All catches and missed catches were recorded. After the five trials were completed, test one concluded, and participants proceeded to test two.

During the second test, catching a tossed ball with both hands, participants were instructed to stand barefoot on the force plate while the examiner stood behind a throwing line, marked with tape, 10 feet in front of the force plate. The examiner tossed a tennis ball to the participants so that it could be caught with both hands between the participant's shoulders and waist. The trial was void and redone if the ball was caught outside this range. If the participants failed to catch the ball, the attempt was recorded, and the participants were instructed to ignore the ball and remain standing on the force plate. The examiner and participants went through one practice attempt to ensure an understanding of the task before beginning the test. Each of the five trials began with a ten-second quiet stance to record baseline data following the same procedure above. Immediately following the quiet stance, one trial of tossing and catching the tennis ball was completed. After either attempting or completing the catch, the participants completed another ten-second quiet stance following the previously stated procedure. This procedure was repeated for five trials. Test two concluded at the completion of all five trials, and the participants moved on to test three.

During the third test, dropping and catching a ball with one hand, participants followed a similar procedure to test one, except for holding, dropping, and catching the ball with only the participant's dominant hand (the one they use to write). All participants stood barefoot on the force plate while holding a tennis ball in their dominant hand with their arm extended in front of their body while their other hand and arm were by their side. The participants then dropped the ball, let it bounce once, and caught it with one hand. The drop and attempted catch constituted one trial. Before beginning the test, the examiner demonstrated the task, and the participants completed one practice attempt to ensure understanding. After the practice attempt, the test began. Each of the five trials began with a ten-second quiet stance to record baseline data following the procedures above. Immediately following the quiet stance, the participants completed a trial of dropping and catching the ball with one hand. After attempting or completing the catch, the participants completed another 10-second quiet stance. Test three concluded at the end of the five trials, and participants then moved on to test four.

For the last test, catching a tossed ball with one hand, participants followed a similar procedure to test two, except for catching the ball with the participant's dominant hand (the one they used to write). The participants stood barefoot on a force plate while the examiner stood behind a throwing line marked with tape 10 feet in front of the force plate. The examiner tossed the tennis ball to the participants so that it could be caught with their dominant hand in between their shoulders and waist. The trial was void and redone if the ball was caught outside of this range. If the participants failed to catch the ball, the attempt was recorded, and the participants were instructed to ignore the ball and remain standing on the force plate. The examiner and participants completed one practice attempt to ensure an understanding of the task before starting the test. After the practice attempt, the first test trial began with a ten-second quiet stance following the procedure above to record baseline data. After the quiet stance, the participants completed one trial of catching a tossed ball, immediately followed by another ten-second quiet stance following the previous procedure. This procedure will be repeated for five trials. At the end of the five trials, all testing was concluded.

Data Analysis

COP data from the force plates in the mediolateral direction was processed in Excel for all tests and trials. Several measures of variability were identified and analyzed. These measures are identified in Figure 1. First, the mean COP and standard deviation (SD) were calculated during the first ten seconds of each trial during the quiet stance. This data gives a measure of variability during static postural control, with lower SD indicating greater postural control and higher SD indicating less postural control. Second, the number of SDs encompassing the quiet stance data was identified for each trial by adding/subtracting the SD from the mean until most of the data was encompassed. This range was deemed the “normal quiet stance range.” This data was later used to compare the total COP range. Third, the COP range was identified by calculating the difference between the maximum and minimum COP values. This measurement identifies the maximum distance the COP moved during each trial. Fourth, the COP range was divided by the SD of the quiet stance to identify the COP/SD ratio. This ratio gives a relative measure of the COP range after the perturbation compared to the average range of the quiet stance. Lastly, the duration of the perturbation effect was identified as the time between the first instance the COP left the normal quiet stance range and the last instance the COP was outside the range after the largest COP measurement. The correlation between all measures and the functional ability scores of each test were identified and compared to determine the best measure to use when linking postural control and functional ability.

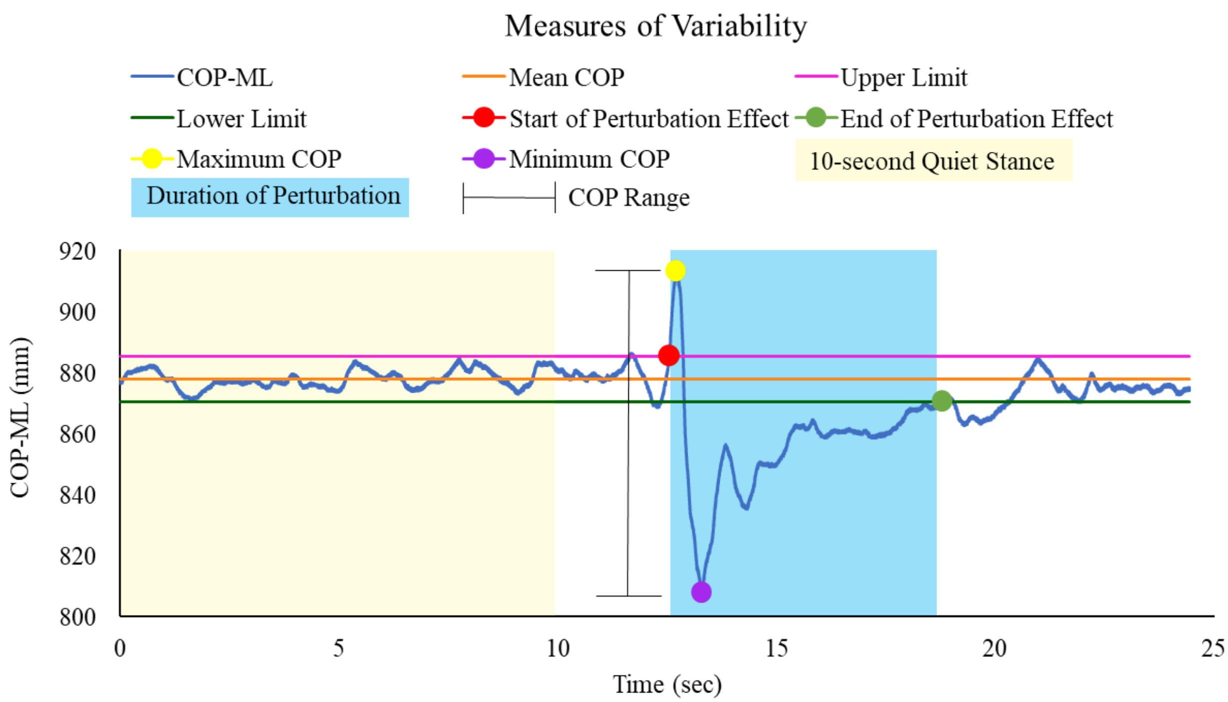

Figure 1. ***Identification of Measures of Variability.*** The graph above identifies the various measures outlined in the Data Analysis section. The participants' COP movement is illustrated using the COP-ML line. The mean COP during the 10-second quiet stance (the yellow section) is illustrated using the Mean COP line. The SD of the COP was also identified during this period. The Upper and Lower Limit lines illustrate the normal quiet stance period, which identifies how many SDs encompass the majority of the quiet stance period. The COP Range is illustrated as the distance between the Maximum and Minimum COP points. The COP range and quiet stance SD were used to identify the COP/SD ratio which is not pictured on the graph. Finally, the duration of the perturbation effect is illustrated in the blue section from the start to end point of the perturbation effect.

Results

To establish a methodology for linking postural stability and functional ability in children with CP, mediolateral COP data was collected during four different tests, and different variability measures were analyzed to identify which were best to use. The measures identified were SD, the number of SDs encompassing the quiet stance, COP range, COP/SD ratio, and the total time of deviation due to the perturbation effect.

Table 1 demonstrates standard deviation measurements for the 10-second quiet stance period at the beginning of each trial. The average SD for each test was identified. The results from all test sessions were later correlated with the functional test scores, illustrated in Table 6.

Table 1.

Standard Deviations of the Quiet Stance Period

		Session 1		Session 2		Session 3	
Test	Trial Number	SD (mm)	Average (mm)	SD (mm)	Average (mm)	SD (mm)	Average (mm)
Test 1: Dropping and Catching a Ball with Two Hands	1	X	4.596292	2.522	2.295651	X	21.56801
	2	2.978		2.371		27.262	
	3	4.5742		3.086		22.292	
	4	5.3409		1.784		15.120	
	5	5.492		1.716		21.598	
Test 2: Catching a Tossed Ball with Two Hands	1	8.4827	5.915921	X	3.126336	15.158	25.80778
	2	6.1701		4.172		31.895	
	3	9.6708		3.110		22.809	
	4	2.9857		2.047		32.839	
	5	2.2703		3.177		26.338	
Test 3:	1	4.5876	3.096587	1.936	3.651353	21.765	29.07013

Dropping and Catching a Ball with One Hand	2	1.583		4.249		37.450	
	3	4.1356		5.522		27.636	
	4	1.5298		3.823		16.903	
	5	3.6469		2.727		41.597	
Test 4: Catching a Tossed Ball with One Hand	1	2.5596	3.52874	4.036	4.562089	30.550	29.72713
	2	3.5831		3.546		30.765	
	3	2.3577		3.196		35.341	
	4	5.2914		3.729		39.347	
	5	3.8518		8.303		12.632	

Note. An "X" indicated that data could not be collected for that trial.

Table 2 demonstrates the number of SDs that encompass the quiet stance. This subjective measure was identified by finding how many SDs above and below the mean all the quiet stance data fell into. The averages of each test session were later correlated with the functional test scores, illustrated in Table 6.

Table 2.

Number of SD's Encompassing Quiet Stance

		Session 1		Session 2		Session 3	
Test	Trial Number	Number of SD's	Average	Number of SD's	Average	Number of SD's	Average
Test 1: Dropping and Catching a Ball with Two Hands	1	X	2.375	2.5	2.5	X	1.75
	2	2.5		2.5		2	
	3	2.5		2.5		2	
	4	2.5		2.5		1.5	
	5	2		2.5		1.5	

Test 2: Catching a Tossed Ball with Two Hands	1	2	2.2	X	2.25	1.5	1.7
	2	2		2.5		2	
	3	2		2		1.5	
	4	2.5		2		2	
	5	2.5		2.5		1.5	
Test 3: Dropping and Catching a Ball with One Hand	1	1.5	2.4	2.5	2.5	1.5	1.6
	2	2.5		2.5		1.5	
	3	2.5		2.5		2	
	4	3		2.5		1.5	
	5	2.5		2.5		1.5	
Test 4: Catching a Tossed Ball with One Hand	1	2.5	2.2	2	1.9	1.5	1.6
	2	2.5		1.5		1.5	
	3	2.5		2.5		1.5	
	4	2		2		2	
	5	1.5		1.5		1.5	

Note. An "X" indicated that data could not be collected for that trial.

Table 3 illustrates the range of the center of pressure, which measures how far the COP moved during the entire trial. This was identified by finding the difference between the lowest and highest COP measurements. The averages of each test were later correlated with the functional scores, illustrated in Table 6.

Table 3.

Range of Center of Pressure

		Session 1		Session 2		Session 3	
Test	Trial Number	Range of COP	Average (mm)	Range of COP	Average (mm)	Range of COP	Average (mm)

		(mm)		(mm)		(mm)	
Test 1: Dropping and Catching a Ball with Two Hands	1	X	89.40775	114.786	73.8652	X	112.966
	2	105.337		67.903		101.51	
	3	71.776		52.416		119.525	
	4	79.967		75.125		147.743	
	5	100.551		59.096		83.087	
Test 2: Catching a Tossed Ball with Two Hands	1	229.194	168.093	X	36.67275	140.092	153.315
	2	255.716		53.379		128.213	
	3	157.176		46.344		150.099	
	4	66.104		24.466		194.222	
	5	132.275		22.502		153.951	
Test 3: Dropping and Catching a Ball with One Hand	1	53.033	53.8986	55.107	108.9256	95.267	159.461
	2	72.973		288.072		197.318	
	3	37.669		49.717		144.507	
	4	55.764		92.114		154.718	
	5	50.054		59.618		205.494	
Test 4: Catching a Tossed Ball with One Hand	1	32.518	35.986	89.978	100.0662	155.299	184.822
	2	49.504		73.492		234.539	
	3	35.928		104.835		182.934	
	4	43.880		137.376		194.762	
	5	18.100		94.650		156.575	

Note. An “X” indicated that data could not be collected for that trial.

Table 4 illustrates the COP/SD ratios, which use the SD of the quiet stance measurements from Table 1 and the COP range measurements from Table 3. The ratio measures COP movement after the perturbation relative to the COP movement during the quiet stance. The averages of each test session were later correlated with the functional scores, illustrated in Table 6.

Table 4.

COP/SD Ratios

		Session 1		Session 2		Session 3	
Test	Trial Number	COP/SD Ratio	Average	COP/SD Ratio	Average	COP/SD Ratio	Average
Test 1: Dropping and Catching a Ball with Two Hands	1	X	21.086	45.513	33.540	X	5.676
	2	35.371		28.644		3.724	
	3	15.691		16.985		5.362	
	4	14.972		42.111		9.771	
	5	18.309		34.446		3.847	
Test 2: Catching a Tossed Ball with Two Hands	1	27.019	33.024	X	11.683	9.242	6.320
	2	41.444		12.795		4.020	
	3	16.253		14.900		6.581	
	4	22.140		11.955		5.914	
	5	58.262		7.083		5.845	
Test 3: Dropping and Catching a Ball with One Hand	1	11.560	23.389	28.466	30.245	4.377	5.794
	2	46.099		67.798		5.269	
	3	9.109		9.004		5.229	
	4	36.452		24.096		9.153	
	5	13.725		21.859		4.940	
Test 4: Catching a Tossed Ball with One Hand	1	12.704	10.950	22.292	24.812	5.083	7.046
	2	13.816		20.723		7.624	
	3	15.238		32.806		5.176	

	4	8.293		36.841		4.950	
	5	4.699		11.399		12.395	

Note. An "X" indicated that data could not be collected for that trial.

Table 5 illustrates the durations of the perturbation effect in each trial. This identifies how long it took participants to recover from the perturbation. The methodology used could not accurately be applied to some trials, resulting in several trials without data.

Table 5.

Time Lapse of the Perturbation Effect

		Session 1		Session 2		Session 3	
Test	Trial Number	Time (seconds)	Average (seconds)	Time (seconds)	Average (seconds)	Time (seconds)	Average (seconds)
Test 1: Dropping and Catching a Ball with Two Hands	1	X	6.852	1.68	4.049	X	X
	2	6.236		1.467		X	
	3	8.049		X		X	
	4	1.861		4.74		X	
	5	11.262		8.312		X	
Test 2: Catching a Tossed Ball with Two Hands	1	3.607	2.079	X	6.182	X	X
	2	2.091		1.831		X	
	3	1.504		10.814		X	
	4	1.116		1.399		X	
	5	X		10.685		X	
Test 3: Dropping and Catching a Ball with One Hand	1	1.358	3.879	X	8.777	X	X
	2	1.029		11.028		X	
	3	6.364		8.758		X	
	4	3.174		6.546		X	

	5	7.472		X		X	
Test 4: Catching a Tossed Ball with One Hand	1	1.407	2.419	14.27	12.417	X	X
	2	4.793		10.015		X	
	3	1.059		X		X	
	4	X		X		X	
	5	X		12.967		X	

Note. An "X" indicated that data could not be collected for that trial.

Table 6 combines the average test scores for each measure and the functional scores related to each test. A correlation coefficient was calculated for each measure in order to compare each methodology.

Table 6.

Correlation Coefficient of Different Measures

		Session 1			Session 2			Session 3		
Measure	Test	Averages	Functional Score	R	Averages	Functional Score	R	Averages	Functional Score	R
Quiet Stance SD	1	4.59629	5/5	-0.548	2.295651	5/5	-0.747	21.568	5/5	-0.557
	2	5.91592	1/5		3.126336	2/5		25.8078	4/5	
	3	3.09659	5/5		3.651353	3/5		29.0701	5/5	
	4	3.52874	2/5		4.562089	0/5		29.7271	2/5	
Normal Range of Quiet Stance	1	2.375	5/5	0.976	2.5	5/5	0.756	1.75	5/5	0.471
	2	2.2	1/5		2.25	2/5		1.7	4/5	
	3	2.4	5/5		2.5	3/5		1.6	5/5	

	4	2.2	2/5		1.9	0/5		1.6	2/5	
COP Range	1	89.40775	5/5	-0.476	73.8652	5/5	0.343	112.966	5/5	-0.770
	2	168.093	1/5		36.67275	2/5		153.315	4/5	
	3	53.8986	5/5		108.9256	3/5		159.461	5/5	
	4	35.986	2/5		100.0662	0/5		184.822	2/5	
COP/SD Ratio	1	21.086	5/5	-0.181	33.54	5/5	0.840	5.676	5/5	-0.990
	2	33.024	1/5		11.683	2/5		6.32	4/5	
	3	23.389	5/5		30.245	3/5		5.794	5/5	
	4	10.95	2/5		24.812	0/5		7.046	2/5	
Duration of the Perturbation Effect	1	6.852	5/5	0.824	4.049	5/5	-0.611	X	5/5	X
	2	2.079	1/5		6.182	2/5		X	4/5	
	3	3.879	5/5		8.777	3/5		X	5/5	
	4	2.419	2/5		12.417	0/5		X	2/5	

Note. An “X” indicated that data could not be collected for that trial.

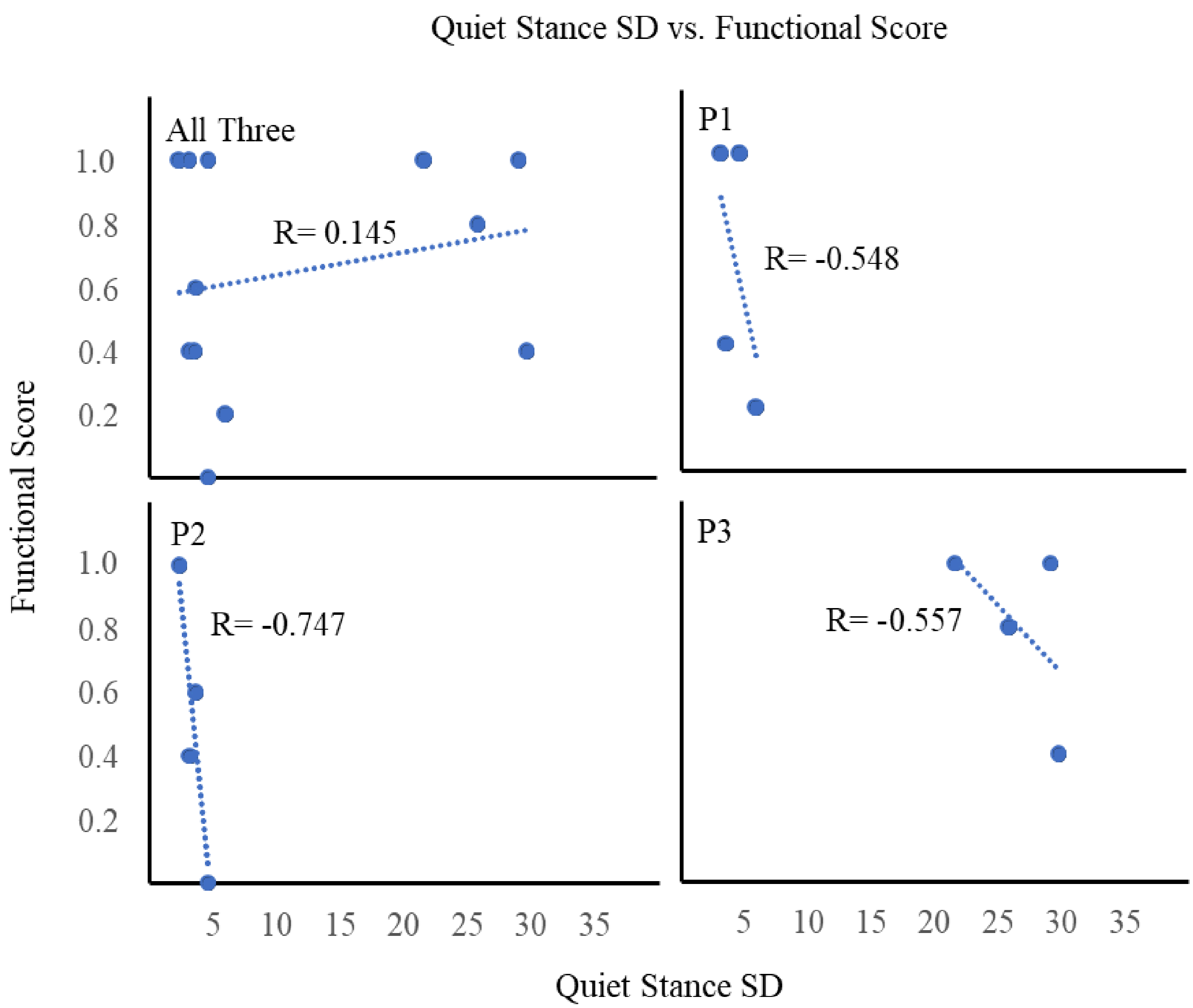

Figure 2. ***Correlation of Quiet Stance SD and Functional Scores.*** The four graphs demonstrate the correlation between the quiet stance SD data and the functional scores of each test. P1, P2, and P3 refer to the data for test sessions one, two, and three. All the data was combined in the "All Three" graph to examine group behavior. In each individual graph a negative correlation was identified. However, the combined graph illustrates a negligible correlation.

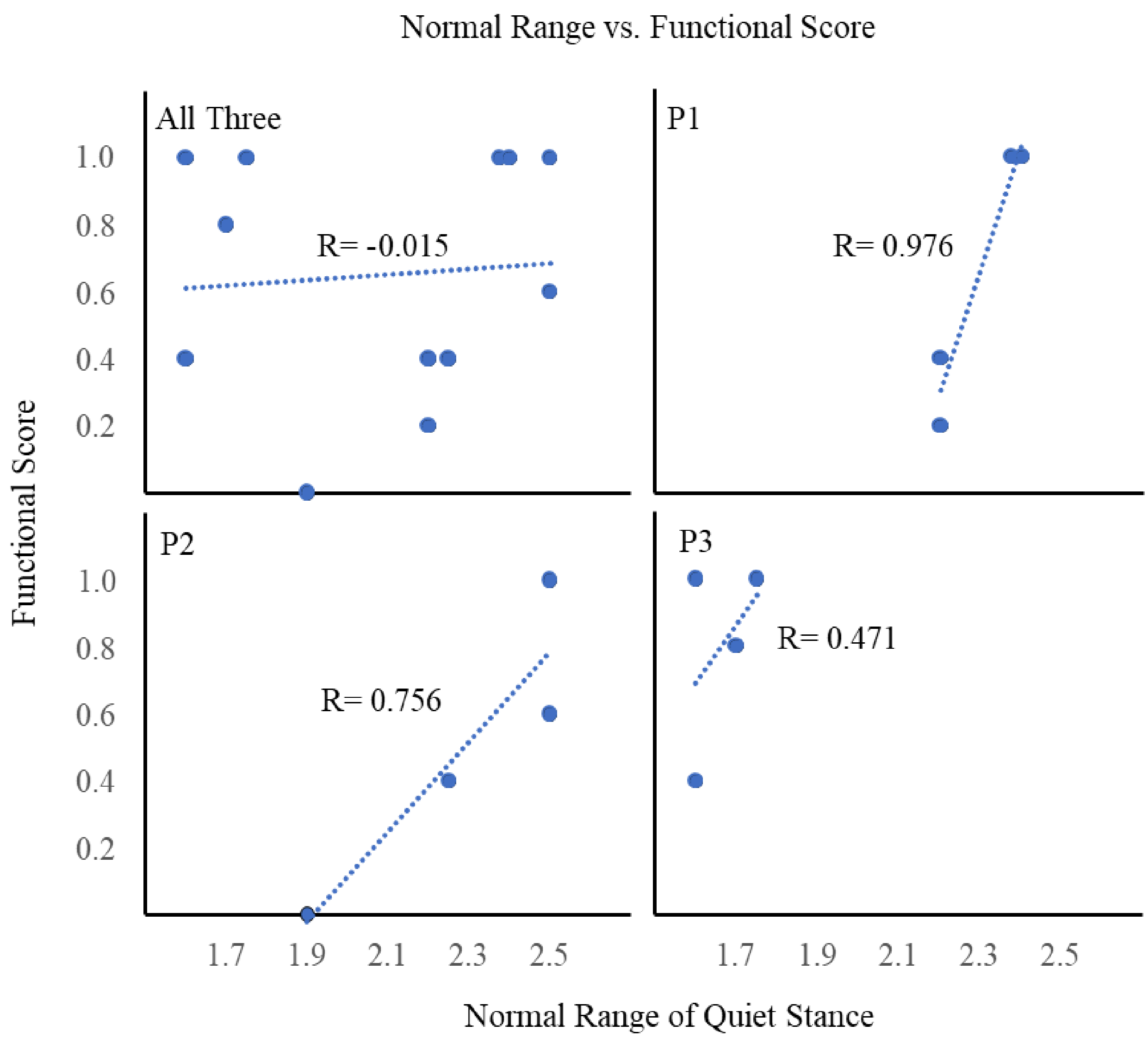

Figure 3. ***Correlation of the Normal Ranges and Functional Scores.*** The four graphs demonstrate the correlation between the quiet stance data's normal range and the functional scores of each test. P1, P2, and P3 refer to the data for test sessions one, two, and three. All the data was combined in the "All Three" graph to examine group behavior. All individual graphs demonstrate a positive correlation, while the combined graph demonstrates a negligible correlation.

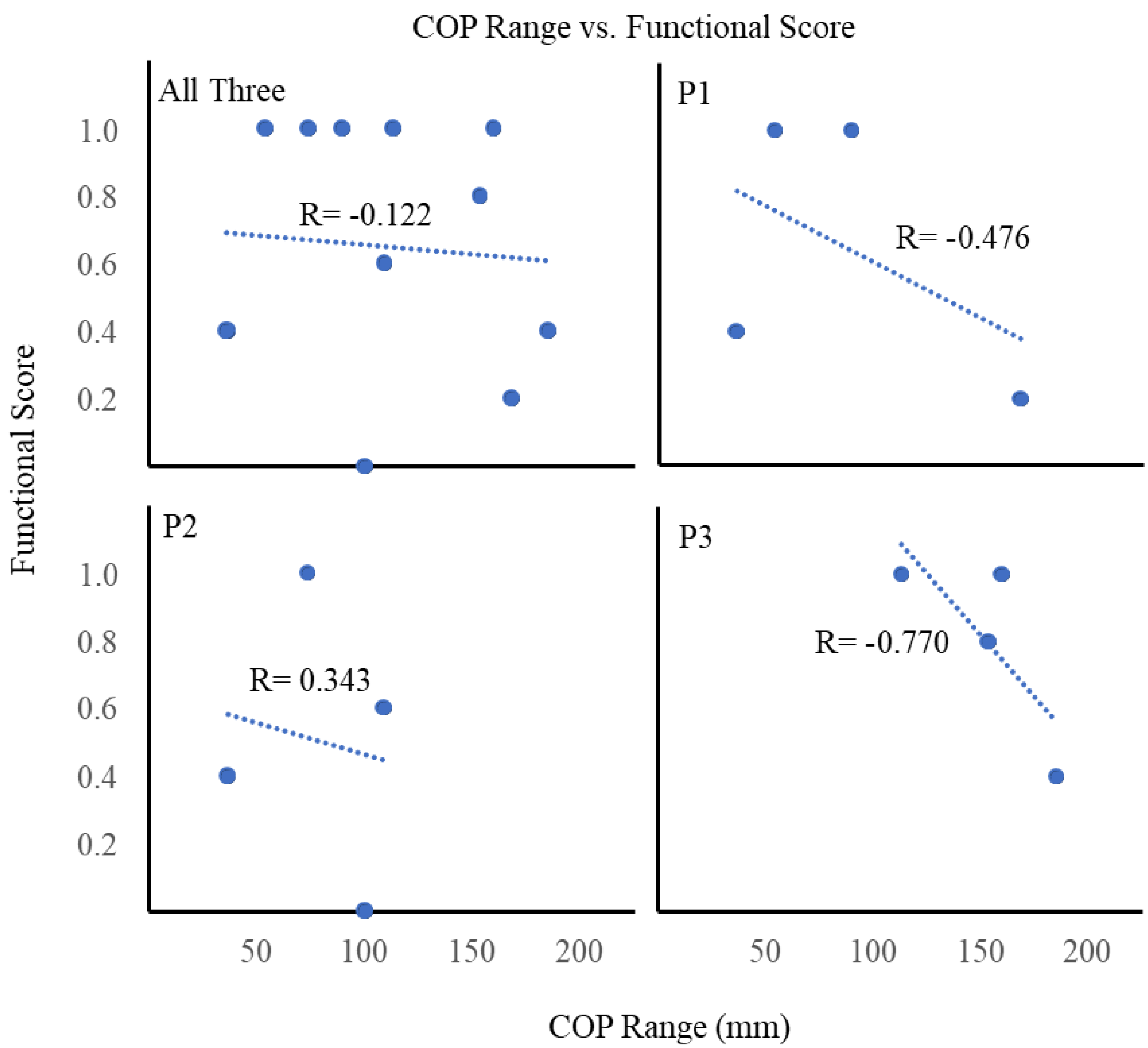

Figure 4. ***Correlation of COP Ranges and Functional Scores.*** The four graphs demonstrate the correlation between the COP range data and the functional scores of each test. P1, P2, and P3, refer to the data for test session one, two, and three, respectively. All the data was combined in the "All Three" graph to examine group behavior. The individual's graphs demonstrate both negative and positive correlation, while the combined graph demonstrates a negligible correlation.

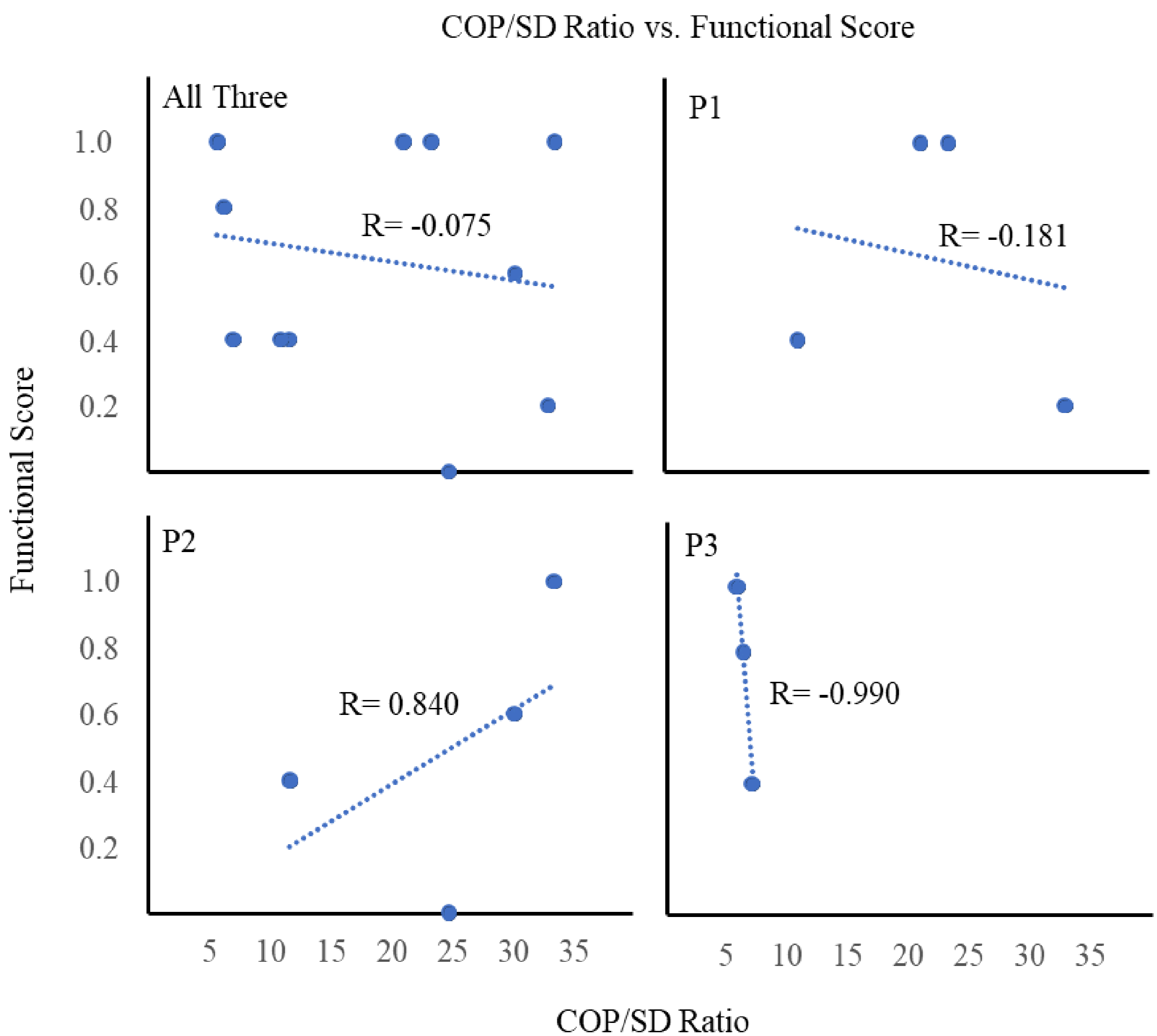

Figure 5. ***Correlation of the COP/SD Ratios and Functional Scores.*** The four graphs demonstrate the correlation between the COP/SD ratio data and the functional scores of each test. P1, P2, and P3 refer to the data for test session one, two, and three. All the data was combined in the "All Three" graph to examine group behavior. The individual graphs demonstrate negligible, positive, and negative correlations, while the combined graph demonstrates negligible correlation.

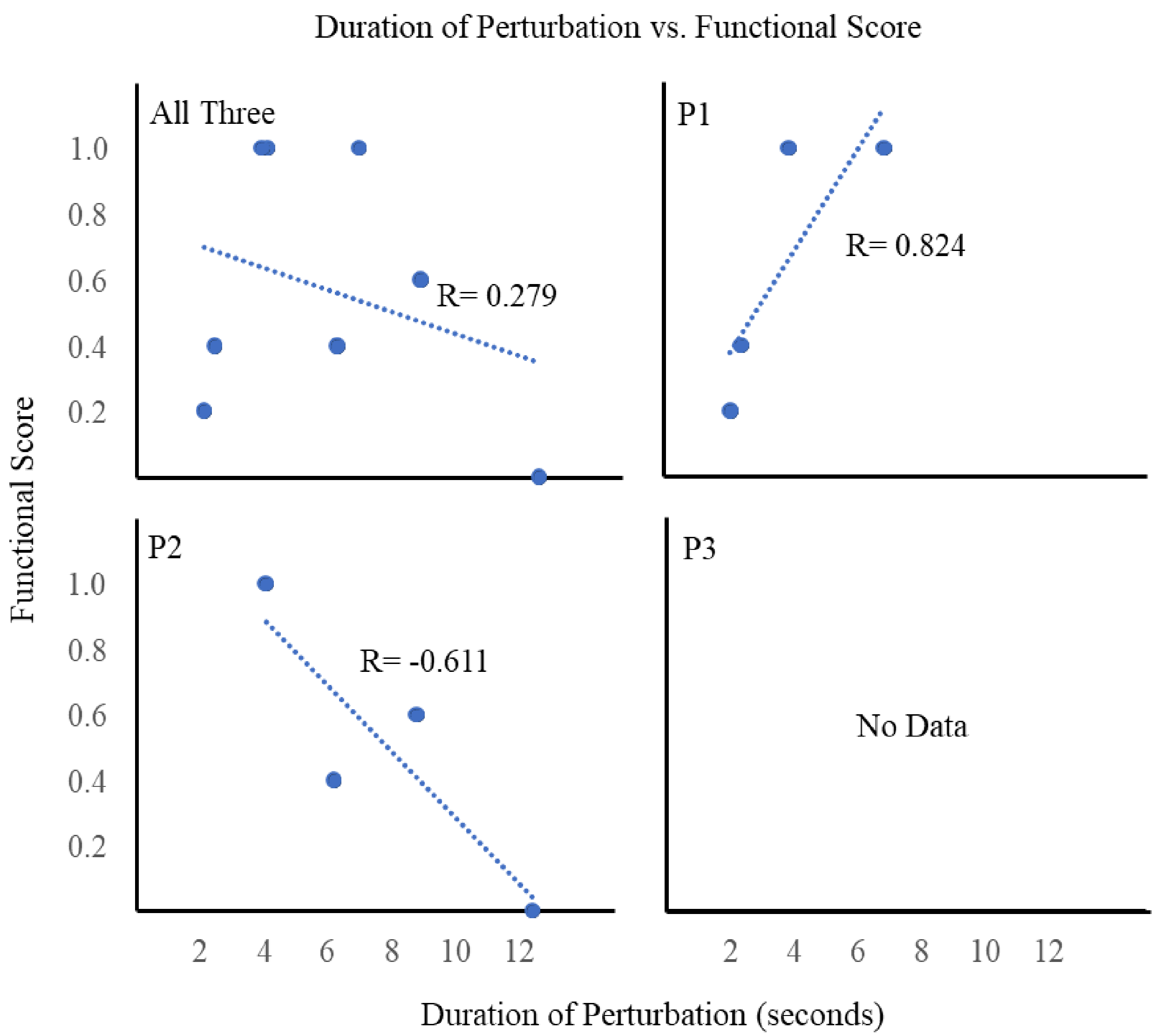

Figure 6. ***Correlation of the Duration of the Perturbation Effect and Functional Scores.*** The four graphs demonstrate the correlation between the duration of the perturbation data and the functional scores of each test. P1, P2, and P3 refer to the data for test session one, two, and three. All the data was combined in the "All Three" graph to examine group behavior. P1 and P2 demonstrate positive and negative correlations, while data could not be collected for P3. The combined graph demonstrates a negligible correlation.

Discussion

The purpose of this study was to develop a methodology for linking postural control and functional performance for children with CP. Mediolateral COP data was collected from force plate data during different tests. The SD of the quiet stance, the normal range of the quiet stance, the COP range, and the duration of the perturbation effects were identified and analyzed by observing the correlation coefficient (R) regarding the functional scores of the BOT-2 test. The measures were evaluated to identify the best means to link postural control and functional ability for future research.

Quiet Stance SD

The quiet stance SD scores had an R-value of -0.548, -0.747, and -0.557 for test sessions one, two, and three, respectively. A visual representation of these correlations can be seen in Figure 2. This indicates a moderate to high negative correlation, meaning that as the SD decreases, the functional score increases. This is expected because a lower SD means that the participant's COP was more consistent and indicated greater postural control, resulting in higher functional ability. These observations are consistent with the study by Pavao et al. (2014), where they reported that as postural control ability increased, so did GMF. When the data was combined, the R-value was 0.145. This indicates a negligible correlation, likely due to an extremely small sample. The collective evaluation of all data does not reflect the individual characteristics, demonstrating that quiet stance SD would be a good measure for future research.

Normal Range of Quiet Stance

The normal range of the quiet stance had R-values of 0.976, 0.756, and 0.471 for test sessions one, two, and three, respectively. A visual representation of these correlations can be seen in Figure 3. This indicates a low to very high positive correlation, meaning that as the range of the quiet stance increased, the functional score also increased. This is not an expected result because the range should be smaller if the participant has greater postural control and functional scores, as supported by Pavao et al. (2014). This contradiction means this measure would not link functional ability and postural control well. Additionally, when the data was combined, the resulting data had an R-value of -0.015, indicating a negligible correlation. This again indicated that our sample size was not large enough to demonstrate group behavior.

Range of COP

The COP range had R-values of -0.476, 0.343, and -0.770 for test sessions one, two, and three, respectively. A visual representation of these correlations can be seen in Figure 4. These values indicate various correlations across the three test sessions: low negative, low positive, and high negative correlations. A negative correlation would be expected because individuals with greater postural control would have smaller changes in their COP and higher functional ability, as supported by Pavao et al. (2014). While the R-values are not extremely high, the two test sessions with a negative correlation demonstrate the potential for this measure to link functional ability and postural control. When the data was combined, the R-value was -0.122, indicating negligible correlation and demonstrating the lack of ability to demonstrate group behavior. The lack of consistency in correlation could also result from a small sample size.

COP/SD Ratio

The COP/SD ratio had R-values of -0.181, 0.840, and -0.990 for test sessions one, two, and three, respectively. A visual representation of these correlations can be seen in Figure 5. This measure also indicated various correlations: negligible, high positive, and very high negative. The inconsistent data is likely due to the ratio not being an accurate measure of functional ability. Because this measure is a ratio, one participant could have a large COP range and SD (indicating poor postural control) with a ratio of 10:10. In contrast, another participant could have a small COP range and SD (indicating good postural control) with a ratio of 5:5. When comparing the ratio between the two participants it would be the same (10:10 vs. 5:5). When the data was combined, the R-value was -0.075. The low consistency of correlational values indicated that this would not be a great measure to link postural control and functional ability. The low sample size could impact the consistency, but it cannot be verified without a larger study.

Time Lapse of Perturbation

The duration of the perturbation effect had R-values of 0.824 and -0.611 for test sessions one and two, respectively. A visual representation of these correlations can be seen in Figure 6. This indicates a high positive and a moderate negative correlation. The duration of perturbation effect could not be calculated for test session three and, therefore, had no data. When sessions one and two were combined, the resulting R-value was 0.279. This indicates a negligible correlation. While the conflicting correlation values of the individual sessions may indicate that duration is a poor measure, the combined correlation coefficient was the largest of all the measures. This measure only uses two participants, decreasing the small sample size even more, which could impact the reliability of these results. Additionally, the high difficulty of obtaining good data for this measure is another reason why this measure may not be useful in future research.

The measure with the highest correlation to the functional scores was the normal range of the quiet stance. However, it was not in line with the expected behavior of the data. The normal range should get smaller as the functional ability increases. This expected behavior is demonstrated in the study by Pavao et al. (2014) and Liao & Hwang (2003); whereas postural control ability increases, motor function also increases. As a result, this measure would not be the best to use when linking postural control and functional ability. The best measure to use would be the SD of the quiet stance. This measure had a moderate to high correlation in the expected direction. One drawback to this measure is that it measures static postural control and cannot consider perturbation. While static postural control is a good measure of postural stability (Rose et al., 2002; Shim et al., 2002), this measure could still be improved upon by increasing its authenticity to real-life scenarios where perturbations occur. The best measure that considers the perturbation would be the range of the COP because the range is not limited to the period of the quiet stance. While this measure had conflicting correlations, the two negatively correlated test sessions indicate the potential for its use as a good measure in future research to link postural control and functional ability.

Using SD of the quiet stance or the COP range in the methodology to link postural control and GMF will provide future researchers with the means to evaluate this relationship and help medical professionals improve rehabilitation services and therapies to improve functionality and participation in life activities. The importance of improving functionality in children's ability to participate in ADLs is demonstrated in the study by Pashmdarfard and Amini (2017). This methodology will help provide a targeted approach to rehabilitative services by identifying areas of postural control that need improvement specific to each participant. This will help drastically improve the quality of life of children with CP. This will further expand research and understanding of dynamic postural control in the CP population, specifically mediolateral postural control.

Research in the mediolateral direction has the potential to provide insight into specific unilateral postural control deficits caused by CP. During a perturbation directed in the anterior/posterior direction, it would be expected that the COP shifts forward and backward to absorb the force until coming back to equilibrium. In the same scenario, minimal or equal COP changes in the mediolateral direction would be expected. In this study, trends were observed that participants' COP often had greater mediolateral changes in one direction than the other. This trend demonstrates the potential for these methods to assess CP's specific impact on either side of the body and its role in postural control. Physicians and researchers could use this to quantify the differences in control on each side of the body when maintaining postural control and better prescribe therapies and rehabilitation services that are more specific to the person. Additional research could be done to look at perturbations from different angles to provide further authenticity to real-life scenarios and make them more applicable to various situations.

One limitation of this study was the small sample size of only two participants and three test sessions. While the purpose of the study was to evaluate the use of different measures in linking postural control and functional ability and, therefore, does not require a significant number of participants, having more would have given us a more comprehensive look into different factors that may impact the use of the methodology. When evaluating all participants together, the resultant data did not demonstrate individual characteristics. With more participants, we are hopeful that group behavior will be able to be identified and better evaluated. Additionally, there were a few trials in each session where data was missing due to software issues when recording the data.

In conclusion, the best measures identified for linking postural control and functional ability were the SD of the quiet stance and the COP range. The SD does not account for perturbation forces and, therefore, is not very authentic to real life. The COP range demonstrated potential for linking postural control and functional ability and is more authentic to real-life scenarios. Both are viable options for future research.

References

Bruininks, R. H., & Bruininks, B. D. (2005). *Bruininks-Oseretsky Test of Motor Proficiency Manual* (2nd ed., pp. 51-69). Pearson.

Chen, J., & Woollacott, M. H. (2007). Lower extremity kinetics for balance control in children with cerebral palsy. *Journal of Motor Behavior*, *39*(4), 306–316.

Gross motor function classification system- Expanded & revised. CanChild. Retrieved September 18, 2023, from https://canchild.ca/en/resources/42-gross-motor-function-classification-system-expanded-revised-gmfcs-e-r

Haywood, K., & Getchell, N. (2009). Development of Manipulative Skills. *Life span motor development* (5th ed.). Human Kinetics (pp. 169–188).

Ivanenko, Y., & Gurfinkel, V. S. (2018). Human postural control. *Frontiers in neuroscience*, *12*, 171.

Jansheski, G. (2023, April 23). *Cerebral palsy gross motor classification system.* Cerebral Palsy Guidance. www.cerebralpalsyguidance.com/cerebral-palsy/gross-motor-classification-system/

Kourtessis, T., & Reid, G. (1997). Knowledge and skill of ball catching in children with cerebral palsy and other physical disabilities. *Adapted Physical Activity Quarterly*, *14*(1), 24-42.

Liao, H. F., & Hwang, A. W. (2003). Relations of balance function and gross motor ability for children with cerebral palsy. *Perceptual and Motor Skills*, *96*, 1173-1184.

Pakula, A. T., Braun, K. V. N., & Yeargin-Allsopp, M. (2009). Cerebral palsy: classification and epidemiology. *Physical Medicine and Rehabilitation Clinics*, *20*(3), 425-452.

Parker, R. (2018, July 19). *Fundamentals of Posture and Balance.* Human Kinetics. https://humankinetics.me/2018/07/19/fundamentals-of-posture-and-balance/#:~:text=To%20maintain%20a%20particular%20posture,with%20the%20term%20postural%20contro

Pashmdarfard, M., & Amini, M. (2017). The relationship between the parent report of gross motor function of children with cerebral palsy and their participation in activities of daily livings. *Journal of Modern Rehabilitation*, *11*(2), 93-102.

Pavao, S. L., Barbosa, K. A. F., de Oliveira Sato, T., & Rocha, N. A. C. F. (2014). Functional balance and gross motor function in children with cerebral palsy. *Research in Developmental Disabilities*, *35*(10), 2278-2283.

Rose, J., Wolff, D. R., Jones, V. K., Bloch, D. A., Oehlert, J. W., & Gamble, J. G. (2002). Postural balance in children with cerebral palsy. *Developmental Medicine & Child Neurology*, *44*(1), 58-63.

Shim, D., Park, D., Yoo, B., Choi, J. O., Hong, J., Choi, T. Y., Park, E. S., & Rha, D. W. (2022). Evaluation of sitting and standing postural balance in cerebral palsy by center-of-pressure measurement using force plates: Comparison with clinical measurements. *Gait & Posture*, *92*, 110–115.

Shiratori, T., Girolami, G. L., & Aruin, A. S. (2016). Anticipatory postural adjustments associated with a loading perturbation in children with hemiplegic and diplegic cerebral palsy. *Experimental Brain Research*, *234*, 2967-2978.

Tarfa, H. B., Hassan, A. B., Badaru, U. M., & Abdullahi, A. (2021). Predictors of gross motor function and activities of daily living in children with cerebral palsy. *International Journal of Rehabilitation Research*, *44*(4), 330-335.

Thomas, J.R., Martin, P.E., Etnier, J.L, & Silverman, S.J. (2023). *Research methods in physical activity* (8th ed.). Human Kinetics (p. 336).

Yeo, S.K., & Cacciatore, M.A. (2017). *Standard deviation and variance.* Sage Research Methods. https://methods.sagepub.com/reference/the-sage-encyclopedia-of-communication-research-methods/i13846.xml.