Foot Progression Angle in Relation to Spatiotemporal Parameters of Gait in Children with Cerebral Palsy

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KEYWORDS
foot progression angle, spatiotemporal, dynamic footprint, cerebral palsy, diplegia.

ABSTRACT
OBJECTIVE: This study assessed the difference in the foot progression angle and measure spatiotemporal parameters of gait of children with diplegic cerebral palsy and to examine the relation among foot progression angle of right and left lower limb and spatiotemporal parameters of gait. DESIGN: Cross-sectional and Correlation study. SUBJECTS: Sixty children with spastic diplegia, aged 5 to 8 years. The participants were categorized into 3 age groups of equivalent number: group A (5 to 6 years), group B (6 to 7 years), as well as group C (7 to 8 years). METHODS: Foot progression angle and spatiotemporal parameters of the gait for both feet were evaluated utilizing a dynamic footprint. RESULTS: a moderate negative significant correlation was noted among left FPA and right step length, and right stride length. There was moderate positive significant correlation among left FPA and cadence . A weak non-significant correlation was observed among right and left FPA and gait parameters among three groups. CONCLUSION: foot progression angle assessment and spatiotemporal measurements and the correlation among them can give objective and quantitative data that could be utilized in rehabilitation and clinical evaluations to identify functional deficiencies.

1. Introduction

One of the most prevalent neurological and physical disabilities in children is cerebral palsy (CP). It is a collection of permanent motion and posture disorders caused by non-progressive lesions in the developing brain of the fetus or infant, often accompanied by other conditions like mental retardation, epilepsy, impaired perception, impaired language, in addition to abnormal mental behavior (Sadowska et al., 2020).

Motor problems observed in children with spastic CP include delayed walking, decreased range of motion, high resistance to passive motion, clonus, hyperactive deep tendon reflexes, and a lack of tone change in response to changes in posture (Lee et al., 2013 and Yılmaz et al., 2018)

Patients with CP commonly develop rotational gait problems which impair walking efficiency and function. Children with spastic CP often have rotational problems in their lower limbs, which can be hard to detect with a physical examination alone. It is essential to address these problems since they change the length of the level arm (Simon et al., 2012 and Rethlefsen et al, 2016).

According to Stanger et al. (2008) and Cao et al. (2024), the foot progression angle (FPA) is the angle that is formed between the longitudinal axis of the foot as well as the line of progression of the gait. Specifically, it indicates the deviated rotation of the lower limb during motion, from the femoral head's tip to the foot. It was also described as the angle of the foot in relation to the patients' progressive gait direction (Abd el aziz et al., 2019).

Neurological disorders typically examine relevant measured parameters, including stride length, cadence, along with velocity (Tunca et al., 2017). Children with CP exhibit several kinematic parameters, including walking velocity, stride length, single, double support, and step width, in addition to kinetic parameters such as power, forces, and moments in gait examination (Chang and Sung., 2014).

Children with CP often have abnormal walking patterns. Crouched gait, or diplegic gait, serves as a significant functional indicator in children with spastic diplegic CP due to motor weakness and impaired voluntary motor control (Mooney and Rose 2019)

This study was done to examine the side differences (right and left sides) on FPA values, measure spatiotemporal parameters of gait, and investigate the interrelationship between FPA and spatiotemporal parameters of diplegic

CP children from five to eight years.

2. Materials and Methods:

Subjects:

60 children with diplegic CP took-part in this study. Participants were chosen from both genders. Participants were chosen from the outpatient clinic at the Faculty of Physical Therapy, Cairo University.

Ethical committee at Egypt's Cairo University's Faculty of Physical Therapy approved the study (NO: P.T.REC/012/002665) and ClinicalTrials.gov Identifier: (NCT06603636).

Inclusion criteria:

- Their age ranged from six to eight years.
- Children diagnosed as diplegic and/or hemiplegic CP.
- Children capable of standing and ambulating independently, without the aid of assistive devices (At Level II or III on the Gross Motor Function Classification System (GMFCS)).
- Their spasticity levels ranged from 1 to 1+ based on the Modified Ashworth Scale.
- Children capable of following the instructions and understanding commands provided during the testing process.
- Dynamic footprint was used to assess FPA as well as spatial parameters of gait (step length and stride length).

Exclusion criteria:

- Children with Convulsions.
- Children with fixed contractures of lower limbs.
- Children with surgical procedures in the lower limbs.
- Children with visual and\or auditory disorders.

The main used equipment and tools:

1. Modified Ashworth Scale: was utilized to determine the degree of spasticity.

2. Gross Motor Function Classification System (GMFCS): was utilized to identify children capable of standing and ambulating independently, without the aid of an assistive device.

3. Dynamic Footprint: Dynamic footprint will be used to measure FPA and spatial parameters of gait. The materials that was utilized for measurement and analyses of FPA (Losel et al., 1996 and Nierenberget al., 2019) were:

- A 6-meter-long, 61-centimeter-wide, and 5-millimeter-high walkway.
- A paper measuring 610 cm by 457 cm (20 ft. × 15 ft.) is to be positioned on the walkway.
- Adhesive tape is utilized to secure the paper on the walkway.
- One chair at each end of the paper.
- A tray with a depth of 1 cm that is sufficiently large to hold both feet.
- Colored powder paint as well as talcum powder are mixed in a ratio of 100:1.
- Two wet towels.
- Towel along with wet wipes for foot cleansing are positioned at the far end.
- Artist fixative spray should be applied over subsequent footprints.
- Adhesive transparent contact plastic was applied over each participant footprint.

- Scissors for cutting the adhesive tape used to stabilize the paper.
- Transparent grid consisting of parallel lines.
- Fine 0.5 mm water-soluble pen (non-permanent marker).
- Two stainless steel rulers: one measuring 30 cm while the other 1 meter.
- Transparent plastic protractor.

Procedures of the study:

- <u>Subjects' recruitment:</u>

Prior to recruitment, the researcher conducted a presentation for parents to clarify the study's objectives and methodology. The consent forms were subsequently provided to the parents of the children. Upon collection of the consent forms, the researcher evaluated subjects based on the defined inclusion and exclusion criteria. All eligible children, as determined by the consent form and examination, took part in the study.

The study protocol was clarified to the participants prior to starting of the study:

Dynamic Footprint Procedure:

(1) <u>For measuring FPA:</u> This procedure will be classified into two main phases:

❖ Measurement phase:

- Footprint data was collected using 6-meter lengths of white paper, 45 centimeters in width, for each trail (Losel et al., 1996 et al., 2019 and Abd El Aziz et al., 2019).
- The paper was positioned on an elevated walkway measuring 6 meters in length and 5.
- All lining paper will be affixed with adhesive tape to avoid any slippage.
- A chair was placed at either end of the paper.
- The child will not be distracted by anything which may change the motion pattern.
- Each child was asked to stand barefoot and was permitted to walk over the walkway multiple times to get familiar with the procedure.
- A wet towel was positioned at the base of the chair on both ends.
- A tray with a depth of 1 cm, sufficiently large to accommodate both feet, was positioned at the base of the chair at each end. It contained a composite mixture of colored powder paint as well as talcum powder in a ratio of 100:1, which was utilized to generate the footprints for analysis.
- Children were directed to position both feet on a wet towel and subsequently place them in a tray.
- Excess powder was carefully removed.
- The container was removed, and then the child was directed to stand from the chair and walk at their own speed to the opposite end, maintaining a forward look and sitting down upon arrival to clean their feet with wet wipes as well as a towel.
- After obtaining an adequate footprint, 4 successive mid-gait analysis footprints were determined to remove the phases of acceleration and deceleration. These footprints were sprayed with a fixing agent to avoid smearing and then allowed to dry.
- After drying, a section of adhesive transparent contact plastic was applied over each participant footprint prior to rolling up the 6 m length of paper.
- All trails received lamination to enable repeated measurements.
- Each child's name was written on every paper.

Fig. (1): Dynamic Footprint measurement

Analysis phase:

- The initial footprints were mostly ignored as they originated from a static position, making them not representative of the subject's movement during active movement.
- A 0.5 mm water-soluble pen was utilized, allowing for erasure of marks without causing indentations onto the laminated surface.
- Stainless steel rulers facilitated line drawing, while a transparent plastic protractor allowed for angle measurements with increments of 0.5°.
- A transparent grid, consisting of parallel lines arranged in a simple rectangular format, was superimposed over the footprint.
- The medial aspect of the forefoot and the apex of the hallux were lined up with the longitudinal boundary of the grid. The distance among the top and bottom edges of the grid and the paper border was measured to guarantee parallel positioning of the grid.
- A grid was utilized to delineate a line (A) that represents the apex of the hallux (Figure 2). A parallel line (B) has been drawn at the posterior aspect of the heel, corresponding to line (A), which divides the length of the foot into three equivalent segments, resulting in lines (C) and (D) (Shores, 1980; Singh et al., 2018).
- Using the outer boundaries of the print, the lengths of lines (C) forefoot reference and (D) back foot reference was measured. Each line was bisected, allowing midpoints to be identified.
- The medial along with lateral borders of the complete footprint were established by drawing two lines:
- 1. The most medial surface of the forefoot, excluding the toes, was marked, along with the most medial surface of the heel. A line was drawn to connect these points, thereby establishing the medial surface of the print.
- The most lateral surface of the forefoot, excluding the toes, was delineated, along with the most lateral surface of the heel. The points were interconnected to define a lateral boundary of the print.
- A line (E) was created by joining the midpoints of points C and D.
- Line (E) served as the longitudinal bisector of the foot.
- The intersection of line (E) and line (B) at the heel of the print, designated as point (X), serves as the reference point for linking additional reference lines.
- It was determined that an objectively determined point at the posterior surface of the heel was the most critical location on the heel.

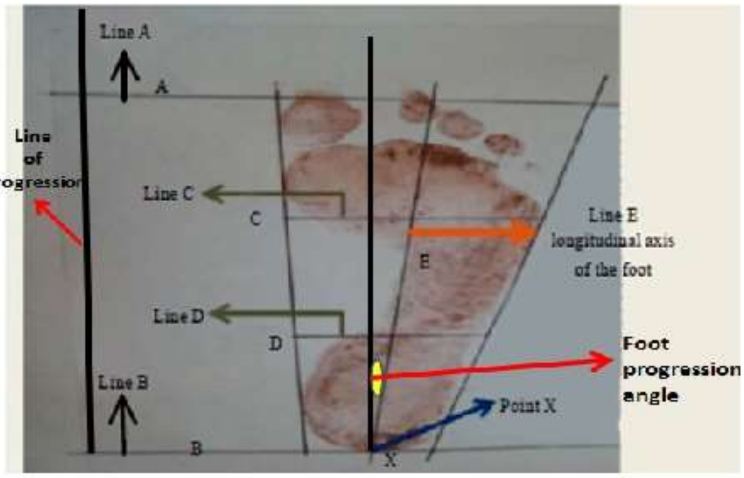

Fig. (2): Foot analysis.

Figure 3. Determining the line of progression

- By connecting the same foot's point (X) to the other's point (X), an ipsilateral line of progression was formed.

- From point (X), a line was made that was perpendicular upon the line of progression on the other side. The perpendicular line is designated as line (H).

- The midpoint of all generated lines (H) was determined and subsequently connected. The line derived from all of the linked midpoints signifies the line of progression (L). This technique generated a progression that varied at each step and estimated a "line of best fit" for the sinusoidal displacement of the center of mass during walking (Wilkinson; Menz, 1997; Singh et al., 2018).

- The FPA was defined as the angle formed between the longitudinal axis of the foot (line E) as well as a line parallel to the line of progression (line L) at point X, as illustrated in Figure 3.

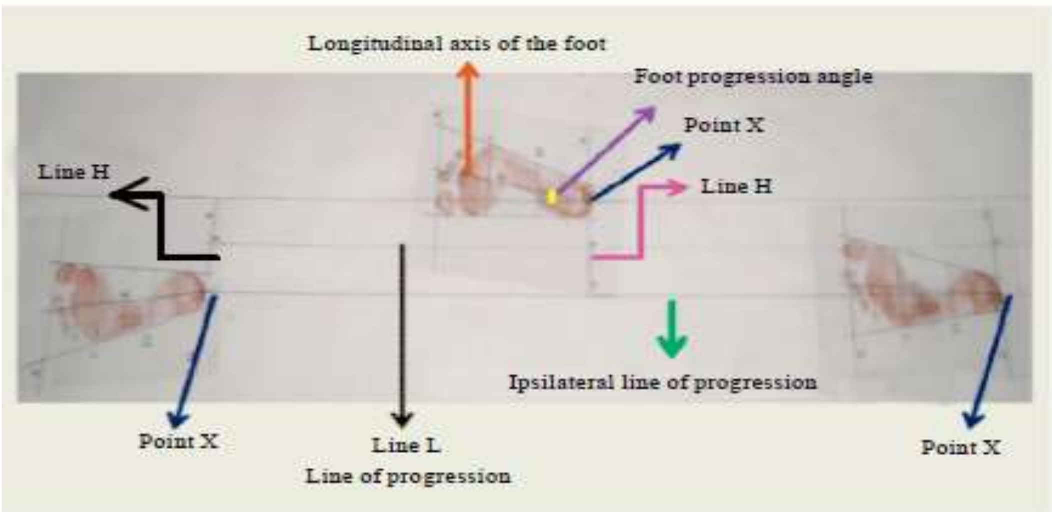

Fig. (3): The foot progression angle.

(2) Measuring Spatiotemporal Parameters:

- Step length was recorded in each participant's walking pattern on a moderately smooth plastered floor. Subjects were instructed to walk barefoot for approximately 50 feet on a plastered floor at their "normal" speed after standing on a pad of old jute bags covered with water-soluble black ink.

- Stride length was recorded on a roll of paper as follows:

A white paper sheet measuring 45 cm in width and 5 m in length was positioned on a flat surface adjacent to a pad constructed from old jute bags saturated with water-soluble, fast-drying black ink. Participants were instructed to stand barefoot on the ink pad and subsequently walk in their natural stride across the sheet. The same procedure was conducted with the subject wearing shoes. The walking pattern of each individual was assessed on two separate times.

The paper sheet contained the individual's name, age, caste, as well as village for identification purposes. After then, stride length was calculated as the linear distance between the heels of two successive footsteps that were the farthest apart. The right stride length was defined as the distance between the right and left footprints. Left stride length, similarly, refers to the distance between the left and right footprints. Walking patterns in which shoes were worn and those in which no shoes were worn were both used for measuring stride length. Four live steps were recorded from each individual's walking pattern to reduce the possibility of abnormal gait. Furthermore, the initial and final steps were removed due to their potential lack of representation of an usual stride (Cassidy, 1980 ; Bennett and Sarita 2014)

- Speed (velocity) The duration required to traverse this distance was documented, and the step length of each stride was quantified as the linear distance among the rearmost point on the heel of two successive footprints (Cassidy, 1980 and Reyes et al., 2016).

Shores (1980) and Gill et al. (2016) documented Step length, stride width, as well as cadence were measured using timed footprint recordings. A piece of commercially accessible, plastic-covered carbon paper has been attached to the floor. The runway measured three full strides of the subject during a practice walk, plus an additional 10 feet (3.048 m). The participant was directed to concentrate on an eye-level target positioned at the end of the runway and to proceed towards it at a standard walking pace. The subject was measured over three complete strides (six steps). Timing started with the initial heel strike following a distance of 3 feet and concluded at the seventh heel strike. A distance of 3 feet (0.914 m) was incorporated both before and after the timing to account for variability in gait resulting from acceleration and deceleration. Participants who could not place their heel on the floor put on street shoes during the assessment. Reference points on each foot were identified by marking the footprint records.

Marks were positioned on each footprint at the most anterior point (point W) as well as the most posterior point on the heel (point X). Parallel lines were formed tangent to points W and X. Point Y represents the bisection of the metatarsal heads. After drawing a line via point W, a line was created connecting points X and Y. A foot's length was measured from the front line to point X, and then divided into thirds. All measurements were made using point Z, which was the line dividing the posterior third from the middle third. Horizontal lines were constructed through point Z, oriented perpendicular to line A, which represents the side of the paper. Line Z was marked with vertical lines that were drawn perpendicular to line A (line B) of the surrounding footprint (line of progression).

- Step length refers to the distance among lines A1 and A2.

- Stride length refers to the distance measured between lines A1 and A3. Stride width refers to the measurement between line B1 and line B2.

- Cadence, measured in steps per minute, is calculated by dividing 360 by the time in seconds required to complete six steps.

- Velocity measured in centimeters per second was calculated by documenting the time taken by an individual to walk "as fast as possible" over a distance of 50 feet (15.24 meters). Participants were directed to walk the entire length of a corridor without the use of pressure-sensitive paper. The initial 50 ft (15.24 m) walking duration in this area was transformed to centimeters per second.

- Single leg support refers to a stage of the gait cycle in which one limb bears all of the body weight whereas the other limb swings forward. This phase typically constitutes 38–40% of the gait cycle (Albaz et al., 2012). The remaining duration is characterized by single support, wherein only one foot maintains contact with the ground (webster et al., 2022).

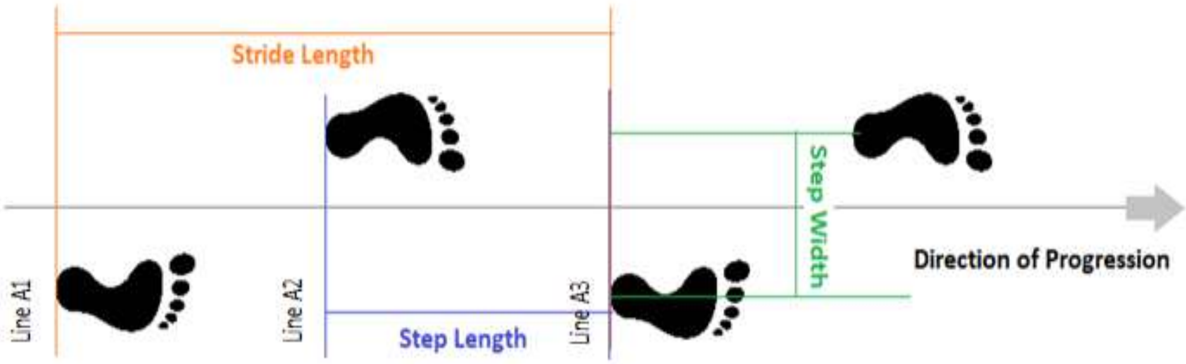

Fig (4): Scoring Step length, Stride length

Statistical analysis:

Descriptive statistics were employed to present the demographic characteristics of the subjects as well as the collected data. correlation coefficient analysis was performed to examine the correlation among FPA and gait parameters. $P < 0.05$ was established as the significance threshold for statistical testing. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 25 for Windows.

3. Results

Subject characteristics:

60 children with diplegic CP took-part in this study. Subjects were distributed into three equivalent groups. Group A was with five to six years, group B was with six to seven years and group C was with seven to eight years.

FPA and gait parameters of study groups:

The mean ± SD value of right FPA of group A, B and C were 5.13 ± 2.13, 5.15 ± 1.59 and 4.35 ± 1.39 degrees respectively; and that of left FPA of group A, B and C were 5.00 ± 1.47, 4.85 ± 1.61 and 5.75 ± 1.45 degrees respectively.

The mean ± SD value of cadence of group A, B and C were 107.85 ± 12.30, 100.70 ± 11.89 and 96.25 ± 12.82 step/min respectively. The mean ± SD value of speed of group A, B as well as C were 0.62 ± 0.06, 0.66 ± 0.08 and 0.65 ± 0.07 cm respectively. FPA and gait parameters presented in table (1).

Table 1. FPA and gait characteristics of study groups.

	Group A	Group B	Group C
	Mean ±SD	Mean ±SD	Mean ±SD
FPA (degrees)			
Right	5.13 ± 2.13	5.15 ± 1.59	4.35 ± 1.39
Left	5.00 ± 1.47	4.85 ± 1.61	5.75 ± 1.45
Right step length (cm)	33.65 ± 2.18	37.43 ± 3.73	39.13 ± 4.09
Right stride length (cm)	68.35 ± 6.12	74.60 ± 7.09	78.03 ± 8.08
Left step length (cm)	36.13 ± 5.13	36.63 ± 3.31	38.45 ± 3.03
Left stride length (cm)	70.80 ± 6.62	73.40 ± 6.09	78.05 ± 4.82
Cadence (step/min)	107.85 ± 12.30	100.70 ± 11.89	96.25 ± 12.82
Speed (m/sec)	0.62 ± 0.06	0.66 ± 0.08	0.65 ± 0.07
Right single support (%)	44.42 ± 4.35	41.56 ± 4.14	40.16 ± 4.04
Left single support (%)	44.89 ± 4.08	41.40 ± 4.78	41.09 ± 4.10

SD, Standard deviation

Correlation between FPA and gait parameters:

A weak non-significant correlation was observed among right and left FPA and gait parameters in group A ($p > 0.05$). (table 2). A weak non-significant correlation was observed among right and left FPA and gait parameters in group B ($p > 0.05$). (table 3). A weak non-significant correlation was observed among right FPA and gait parameters in group C ($p > 0.05$).

There was moderate negative significant correlation among left FPA and right step length ($r = -0.473$, $p = 0.035$), and right stride length ($r = -0.451$, $p = 0.046$). A moderate positive significant correlation was observed among left FPA and cadence (r = 0.517, p = 0.020). (Table 4).

Table 2. Correlation between FPA and gait parameters in group A:

	Right FPA (degrees)		Left FPA (degrees)	
	r value	p value	r value	p value
Right step length (cm)	0.230	0.330	0.085	0.721
Right stride length (cm)	-0.023	0.924	0.009	0.971
Left step length (cm)	0.030	0.901	0.028	0.907
Left stride length (cm)	0.032	0.895	0.115	0.629
Cadence (step/min)	0.094	0.693	-0.048	0.841
Speed (m/sec)	0.220	0.352	-0.055	0.819
Right single support (%)	0.127	0.592	-0.059	0.805
Left single support (%)	0.193	0.415	-0.020	0.934
Left FPA (degrees)	0.294	0.208		

r value: Pearson correlation coefficient; p value: Probability value.

Table 3. Correlation between FPA and gait parameters in group B:

	Right FPA (degrees)		Left FPA (degrees)	
	r value	p value	r value	p value
Right step length (cm)	-0.080	0.736	0.250	0.288
Right stride length (cm)	-0.109	0.648	0.251	0.287
Left step length (cm)	0.026	0.913	0.178	0.452
Left stride length (cm)	-0.121	0.613	0.152	0.522
Cadence (step/min)	0.022	0.927	-0.250	0.287
Speed (m/sec)	-0.074	0.757	0.128	0.592
Right single support (%)	0.011	0.962	-0.230	0.329
Left single support (%)	-0.038	0.874	-0.255	0.278
Left FPA (degrees)	0.235	0.319		

r value: Pearson correlation coefficient; p value: Probability value

Table 4. Correlation between FPA and gait parameters in group C:

	Right FPA (degrees)		Left FPA (degrees)	
	r value	p value	r value	p value
Right step length (cm)	-0.122	0.609	-0.473	0.035*
Right stride length (cm)	-0.124	0.602	-0.451	0.046*
Left step length (cm)	-0.177	0.455	-0.363	0.116
Left stride length (cm)	-0.101	0.671	-0.387	0.092
Cadence (step/min)	0.097	0.684	0..517	0.020*
Speed (m/sec)	0.391	0.088	0.288	0.219
Right single support (%)	0.196	0.407	0.408	0.074
Left single support (%)	0.186	0.434	0.276	0.239
Left FPA (degrees)	0.033	0.891		

r value: Pearson correlation coefficient; p value: Probability value, * significant at $p < 0.05$

4. Discussion

Pathological gait patterns, such as a greater medially oriented foot progression angle (in-toeing) or a greater laterally oriented FPA (out-toeing), are common in children with CP. These patterns might be concerning for practitioners and physicians.

This may impact many gait parameters like spatiotemporal parameters of gait during the gait cycle.

This study was done to examine the side differences (right and left sides) in FPA values in diplegic CP children and to measure spatiotemporal parameters of gait (step length, stride length, speed, cadence, single leg support) in diplegic CP children from five to eight years and to examine the relation between FPA of right and left lower limbs and spatiotemporal parameters of gait in diplegic cerebral palsied children.

The research project aimed to evaluate the foot progression angle and its impact on spatiotemporal parameters of gait for children affected by diplegic CP to help practitioners and clinicians in their interventions.

The present study was performed on 60 children with diplegic CP from both genders with their age ranging from five to eight years old, when children are free to move at their own speed while wearing nothing but their bare feet Abd El Aziz et al., (2019) agreed with the current selected procedure regarding the number of participants needed in this study.

This study focused on diplegic children with CP suffering from gait abnormalities. This corresponds to the findings of Zhou et al. (2017) and Wu et al. (2015), who noted that the diagnosis of CP usually depends on the observation of excessive muscle tone or posture, delayed motor milestones, or the existence of gait deviations in young children, which can vary from mild, such as toe-walking, to severe, such as crouched or medially rotated gait.

Furthermore, Simon et al. (2012) and Sarathy et al. (2019) indicated that rotational gait abnormalities are prevalent among patients with CP, which negatively impacts gait efficiency and overall function. Rotational problems with the lower limbs of children with spastic CP are common and difficult to detect through physical examination alone. These problems alter the level of arm's length and require significant attention. Kim and Son (2014) agreed with this study, indicating that children with spastic diplegic CP exhibit deteriorated gait function and altered gait patterns, as reported in previous research. Bruno et al. (2020) identified that the primary causes of in-toeing gait in patients with diplegic CP are medial rotation of the hip and medial tibial torsion.

Mohamed, (2011) who found that children striates of three equal age groups, group (A) from five to six years, group (B) from six to seven years, and group (C) from seven to eight years is concurrent with the current study.

The children in this study were aged five to eight years, consistent with the findings of Chester et al. (2006) and Malloggi et al. (2021), who noted that pediatric gait data looks similar to adult patterns by about three and a half to four years old, while mature sagittal kinetic patterns within the ankle develop around nine years of age.

Furthermore, Liu et al., (2022) stated that the mean gait angles were shown to increase with age from 4 degrees in the three and six years old to 7 degrees in the nine-year-old and adult period.

The current study concluded that spatial parameters, specifically step length as well as stride length, consistently increase with advancing age and height. In contrast, temporal parameters demonstrated a discontinuity following 7 years of age. The results indicated that step length increased from 33.65 to 39.13, while stride length increased from 68.35 to 78.03 with age. These results align with Thevenon et al. (2015), who discovered that the onset of alterations in gait coordination in children approximately 7 years old is likely attributable to a maturation process. And, Demirbüken et al., (2019) who revealed that; mature plantar pressure distribution is obtained between five and six years of age.

The current study done by using a dynamic foot print which an objective method for evaluating foot progression angle and spatiotemporal parameters of gait in diplegic CP children.

The evaluation methods employed in this study coincide with the findings of Ranawat et al. (2017), who indicate that the FPA is a critical measure for assessing gait abnormalities, including in-toeing and out-toeing, which are prevalent concerns among parents and often lead to multiple visits with pediatricians or orthopedists.

In addition, Caderby et al., (2022) and Losel et al. (1996) comes in agreement with this study that who defined the FPA for evaluation serves as a simple and objective measure to assess changes in a child's gait over the years. This allows the examiner to identify deviations from typical development and serves as a foundation for further investigation into the root causes, which can be readily documented. Abnormalities of gait, including in-toeing and out-toeing, are prevalent concerns in children with diplegic CP. FPA is identified as a cost-effective and valuable instrument in clinical gait analysis.

The evaluation of FPA and spatiotemporal gait parameters in diplegic children with CP in this study aligns with the findings of Carty et al. (2014) and Carriero et al. (2009), who noted that children with CP exhibited increased medial hip rotation in the transverse plane and internal fFPA during stance .

Kong et al. (2018) demonstrated that the FPA in typically developing children evolves in conjunction with the reported reduction in femoral anteversion and the rise in lateral torsion of the lower limbas they age. Anne et al. (2014) reported that abnormal pelvic rotation was linked to abnormal FPA within 68% of children with diplegic CP.

Spatiotemporal parameters are essential measurements for assessments, providing critical information regarding time and position in relation to gait. These parameters can be easily collected during clinical sessions using easy measuring devices. The most frequently utilized spatiotemporal parameters include walking speed, stride length, step length, as well as cadence (Roberts et al., 2017).

Gómez et al. (2023) demonstrated that spatiotemporal parameters represent information regarding the temporal and spatial features of gait, derived from the gait cycle. These parameters include gait speed (m/s), cadence (steps/min), stride time (s), stride length (m), as well as single support (% of gait cycle).

The evaluation of spatiotemporal gait parameters in diplegic children with CP in this study aligns with the findings of Carty et al. (2014) and Carriero et al. (2009), which indicate that children with CP exhibit significantly reduced walking velocity, shorter step lengths, and longer step times compared to their healthy counterparts.

Additionally, according to study by Steele et al. (2012) and Chang et al. (2014), spastic diplegia is characterized by abnormal gait patterns and symptoms such as excessive muscle tone, an apparent imbalance of forces throughout the lower limbs' joints, a lack of selective muscle control, impaired equilibrium reactions, as well as a resistance to passive muscle stretching that increases with velocity in agonistic muscle groups.

Regarding children from five to eight years; results revealed that the mean values of the FPA in the right and left sides between the three groups showed non-significant differences.

The results of this study corroborate those of Akalan et al. (2013), who investigated the differentiation of abnormal gait characteristics caused by excessive femoral anteversion from additional factors in CP, with respect to the mean as well as SD scores of the left and right FPA of three groups. Additionally, children between the ages of 6 and 8 had an average FPA of 5 to 8 degrees .

At 5 to 6 years, the average FPA for the right and left foot was around 5 degrees, according to the present study. Between the ages of six and seven, it increased slightly for the right foot and declined slightly for the left. At 7 or 8 years old, it reduced slightly for the right foot but increased slightly for the left.

Lee et al. (2013) examined the extent to which torsional bone abnormalities contributed to rotational gait characteristics in diplegic CP patients, and their findings were consistent with ours. Between the ages of five and six, they discovered that diplegic CP children had a mean FPA of around 5.5 degrees, while from six to seven years was about 5.8 degree, and in seven to eight years was about 4.2 degrees with no significant differences among age groups.

Regarding children from five to eight years; results revealed that the mean values of the spatiotemporal parameters in the right and left sides between three groups showed a significant difference in right step length, right stride length, right single leg support, left stride length, left single limb support, cadence between the three groups and no significant difference in left step length and speed among the three groups.

The findings of this study are in line with those of Kim and Son (2014), who also found that children with spastic diplegic CP had significantly altered gait characteristics, particularly in terms of reduced spatial-temporal gait parameters like step as well as stride length. The hip abductor muscles are weak in children with spastic diplegic CP, according to reports. As a result, there would be a reduction in time in single-limb support as well as the gait pattern will be unstable.

However, Wang et al. (2015) discovered that spastic diplegic children's gait speeds were significantly lower than those of typically developing children. This may be because these children are frequently classified into level III GMFCS, which is more complex than levels I and II, and hence contradicts the present study's findings.

In the current study the mean and SD values of left and right step length of group three groups were about 0.35 meters, left and right stride length were about 0.75 meters which come in agreement with Darwesh et al., (2019) how explain the mean values of the stride length as well as step length were about 0.67 and 0.33 meters.

Another study that confirmed the current findings is Wang et al. (2015). They found that spastic diplegic children have a significantly reduced cadence, which could be because they are classified at level III GMFCS, that is more engaged than levels I and II.

Sarathy et al. (2019) argued that clinical evaluations of children should include examination of foot pathology throughout walking, which is in line with the study's goals .

Because it is a dynamic foot function thought to be associated with disease, Paterson et al. (2015) also noted that the evaluation technique was developed while walking (examined in the dynamic rather than the static scenario). Also, despite the inherent variability in dynamic situations, dynamic footprints have proven to be more reproducible than static ones, and static measurements do not adequately predict dynamic foot function.

In addition, according to Lin et al. (2001) and Mousafeiris et al. (2023), pediatric foot alignment can be greatly affected by just one abnormality in the lower extremities' dynamic function. Furthermore, it was noted by Lin et al. (2001) and Wang et al. (2024) that the majority of reports tended to concentrate on static anatomical problems rather than on dynamic mechanisms. These dynamic mechanisms include the interaction between FPA, gait parameters, as well as the biomechanics of specific lower-extremity joints, particularly the ankle joints.

The correlation between FPA and spatiotemporal parameters of gait. Results revealed that there was a moderate negative significant correlation among left FPA and right step length, right stride length, and a moderate positive significant correlation of cadence in group C.

The current study results matched with Danino et al., (2015) who demonstrated the significant correlation between the diplegic group's rotational profile (femoral anteversion as well as thigh foot angle) and the FPA during the four stages of the gait cycle (step length, stride length, cadence, as well as velocity).

Simon et al. (2014) described the torsional kinematic profiles of the lower limbs in children with spastic diplegia, and their findings are consistent with the present study. An analysis was conducted on 188 diplegic children who were classified as having type II or III CP based on the GMFCS. Patients' ages ranged from 4.25 to 25 years, with an average of 11.7 years. On average, the results for FPA ranged from 4 to 15 degrees. For medial and lateral rotation, the corresponding values were negative and positive, respectively.

Additionally, they mentioned that an excessive amount of ankle rotation was the cause of a quarter of the FPA abnormalities .

A non-significant association was found among left FPA and all spatiotemporal parameters in groups A and B, along with among right FPA and all spatiotemporal parameters in three different groups.

But in group C, there was a weak but significant relationship between left FPA as well as left stride length, left and right single leg support, speed, and left step length.

5. Conclusion

From the obtained findings of this study, we can conclude that; FPA assessment and spatiotemporal measurements and correlation between FPA and spatiotemporal parameters of gait in CP diplegic children can offer objective and quantitative data that might be included into rehabilitation and clinical evaluation strategies to identify functional abnormalities, select the best method of treatment, and ultimately lead to better management through early intervention.

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