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# Foot Posture in Relation to Gait Parameters in Children with Hemiplegic Cerebral Palsy

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***Abstract:***
***Background:*** *Kinetic as well as kinematic gait impairments are frequent found in children with hemiplegic cerebral palsy (CP). Abnormal foot posture is a common musculoskeletal abnormality that might interfere with the normal pattern of gait among those children.*
***Aim****: The current study intended to examine the foot posture in relation to gait parameters in children with hemiplegic CP.*
***Patients and Methods****: Fifty-two volunteer children with hemiplegic CP, aged from 7 to 11 years, were enrolled in this study. The static foot posture and gait parameters were assessed by Foot Posture Index (FPI-6) and Biodex Gait Trainer 2$^{TM}$, respectively.*
***Results****: There was a negative weak correlation between the foot posture and the walking speed, cadence, the time on the affected side and ambulation index ($r<-0.25$, $p>0.05$). A Positive weak relation was found between the step length of the affected side and foot posture ($r<0.25$, $p>0.05$). Moreover, a significant relation was recorded between the FPI-6 total score and the total distance and the coefficient of variation ($r=-0.29$, $p<0.05$ and $r=0.32$, $p<0.05$, respectively).*
***Conclusion:*** *Static foot posture has limited impact on gait parameters in children with hemiplegic CP. Further studies are recommended to specify the relation between dynamic foot posture and gait parameters in children with hemiplegic CP.*
***Keywords:*** *Cerebral palsy, Hemiplegic cerebral palsy, Gait, Foot posture.*

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## I. Introduction

Locomotion is a crucial daily living task. It is the ultimate product of a series of developmental changes influenced by changing environments and activity demands until reaches the mature adult pattern around the age 6–7. Therefore, development of normal walking pattern requires cortical suppression of primitive reflexes then cortical control on movement execution **[1, 2]**.

Abnormal gait pattern in the pediatrics is related to dysfunction in the continuous interactions amongst many subsystems: individuals' intrinsic characteristics (e.g., genetics, the integrity of the nervous and musculoskeletal structures) and their surrounding environment. Although many of these abnormalities can be monitored and treated conservatively, other gait deviations need more comprehensive strategy for evaluation and treatment **[2]**.

Cerebral palsy (CP) is a widespread movement disability in pediatrics representing non-progressive upper motor neuron lesions (UMNL) of immature brain with worldwide prevalence of 2–3 per 1,000 live births. Spastic hemiplegia, unilateral CP, is a common form representing 38% of all CP **[3-6]**. Postural and motor disorders are common in hemiplegic children including tone abnormalities, postural deviations, delayed motor development and delayed walking with abnormal patterns **[7, 8]**.

Abnormal tone, weakness, lack of motor control, and musculoskeletal disorders such as contractures, joint instability and lower extremity deformities as equinus and intoeing are common impairments in CP. Usually, these impairments don't occur in isolation and significantly affect the general performance of the child especially walking efficiency **[9, 10]**.

Deformities of the foot and ankle are the most common musculoskeletal problem seen in children with spastic CP. The severity and pattern of these deformities is variable and unpredictable in young children because of inconsistent pattern of brain injury and etiology. Static as well as dynamic deformities around the foot-ankle complex are usually observed in children with spastic CP and induce secondary abnormalities in hip and knee joints, as well as in the non-hemiplegic limb. About 25% to 30% of all orthopedic surgeries performed on ambulatory children with CP are performed at the foot-ankle complex to improve gait **[11, 12]**. The most frequent foot malalignments in children with spastic CP are equinus, equino planovalgus, and equinocavovarus **[13]**.

Movement pattern of the child with spasticity are frequently ruled by persistent reflex patterns that have not been integrated into more mature patterns of movement. Children with hemiplegic CP have difficulties with advanced gait activities and gait deviations. The lower extremity tends to turn into internal rotation at the hip and extension at the knee with ankle planter flexion. Moreover, gait is characterized by asymmetry, decreased step length and stride length, poor pelvic and shoulder girdle rotation with retraction, and absence of heel strike on the involved side **[14]**.

Although several studies were conducted to investigate musculoskeletal and neurological factors causing gait impairments in children with CP, limited literature are available regarding the relation between either static or dynamic foot posture and gait among this population. Therefore, the current study intended to explore static foot posture in relation to gait parameters in children with hemiparetic CP. We hypothesized that there would be a linear correlation between gait parameters and static foot posture.

# II. Methods

## 2.1. Study design and setting

A correlational study was conducted from November 2017 to June 2018. The participants were selected form the Outpatient Clinic, Faculty of Physical Therapy, Cairo University; National Institute for Neuro-Motor System and Dar El Salam General Hospital. While the assessment procedures were conducted at the Biodex Gait Trainer 2$^{TM}$ lab, Faculty of Physical Therapy, Cairo University, Egypt.

## 2.2. Ethical aspects

The study procedures were carried out following the Code of Ethics of the World Medical Association (Declaration of Helsinki). Ethical committee approval of the Faculty of Physical Therapy, Cairo University was obtained before starting the study. A signed an informed consent form which signed by the participant's legal guardians giving their acceptance for participation in the study and publication of the results.

## 2.3. Study population

Fifty-two volunteer children, 25 girls and 27 boys, were enrolled in the study if they, had been diagnosed as hemiparetic CP, aged from 7 to 11 years (8.4± 1.2), had spasticity level grade1 and $1^+$ according to Modified Ashworth Scale (MAS), abled to walk independently indoors (level I-II according to Gross motor function classification system [GMFCS]), and abled to understand and follow instructions. Children with fixed malaligments of the lower extremities and/or history of recent fractures, sprain or strain injuries of the lower extremities, neurological and/or orthopaedic surgeries, botulinum toxin injection in the lower extremities in last six to twelve months before the study, and uncontrolled seizures, were excluded.

## 2.4. Sample size estimation

A pilot study was conducted on 10 cases to calculate the appropriate sample size using the G*Power software version 3.1.2 for MS Windows, Franz Faul, Kiel University, Germany. The results indicated that the coefficient of determination between the FPI-6 total score and step length of the affected limb was 0.19. Accordingly, the proper sample sizes were 16. Based on the results, we included 52 children to be able to reject the null hypothesis with 80% power setting type I error probability to 0.05 and for possible dropout.

## 2.5. Foot posture assessment

The static foot posture assessment was conducted by the FPI-6. It is a valid and reliable observational clinical tool that incorporates sagittal, transverse and frontal planes **[15]**. The index composed of six clinical criteria that quantify the degree to which a foot is pronated/supinated with the subject in a standing relaxed bipedal position *(box 1*) **[16]**.

Each assessment criteria were graded on a scale ranging from -2 to +2 and the sum of scores was used to determine foot type. Interpretation of the results was done and recorded as the following: a highly pronated foot posture (+10), pronated foot posture (+6 to +9), normal or neutral foot posture (0 to +5), supinated foot posture (-1 to −4), and finally a highly supinated foot posture (−5 to −12) **[17]**.

**2.6. Kinematic gait parameters**

The Biodex Gait Trainer 2TM was used to assess the gait parameters *(box 2)*. It is a device that can be used for assessment and training walking capability in individuals with gait disorders. It consists of a treadmill with an instrumented deck that estimates several kinematic gait parameters. The assessment procedure was performed according to the standardized manual instructions. Before actual assessment step, familiarization to the device and the assessment procedures were explained for each child with a 3-minute unrecorded trial. Each child took a 3-minute rest before moving to the assessment phase during which the walking speed was to 0.3 meter/hour and was raised gradually allowing the child to accommodate the speed before changing to a higher speed. The data recording process was carried out as the child could walk comfortably without jogging or shuffling at maximum speed of 0.6 meter/hour. Repeating this procedure for three times with one-minute rest after between each trial. A printout for each trial was obtained then calculation and recording the mean of the three trials for data analysis.

## III. Statistical Analysis

All statistical calculations were performed by an experienced biostatistician using SPSS (Statistical Package for the Social Science; IBM Corp, Armonk, NY, USA) release 22 for Microsoft Windows.

Statistical analysis of patient demographics and clinical data were conducted using the Kolmogorov Smirnov test and descriptive statistics were calculated in terms of mean ± standard deviation (SD), range, frequencies (number of cases) and percentages (%) when appropriate.

While correlation between various variables was done using Spearman rank correlation equation, the strength thresholds of the relationships was described by **Portney and Watkins [18]** as 4 degrees including a weak or no relationship (<0.25), fair relationship (0.25–0.50), moderate to good relationship (0.50–0.75) and a good to excellent relationship (>0.75). P values less than 0.05 was considered statistically significant.

## IV. Results

Descriptive statistics for the FPI-6 total score and spatio-temporal gait parameters are presented in Table (1). The correlation between the FPI-6 total score with spatio-temporal gait parameters are summarized in Table (2) and illustrated in Figure (1).

There was a negative weak correlation between the FPI-6 total score and the walking speed (m/sec), cadence (cycle/sec), the time on the affected side (%) and ambulation index ($r<-0.25$, $p>0.05$). A Positive weak relation was found between the step length of the affected side (m) and the FPI-6 total score ($r<0.25$, $p>0.05$). Moreover, a significant relation was recorded between the FPI-6 total score and the total distance (m) and the coefficient of variation ($r=-0.29$, $p<0.05$ and $r=0.32$, $p<0.05$, respectively).

## V. Discussion

Children with spastic hemiplegic CP exhibit several musculoskeletal abnormalities of the lower extremities that result in gait and balance disorders. Deformities around the foot-ankle complex might be either fixed or, in mild cases, dynamic. Up to our knowledge, this is the first study to investigate the static foot posture in relation to gait parameters in children with hemiplegic CP.

In a child with spastic CP, the relationships between the different symptoms of the upper motor neuron lesions; weakness, spasticity, coactivation, loss of movement selectivity; and gait parameters or effective performance remain debatable. Whether equally or independently distributed, and which impairments are cause the abnormal gait pattern and limitation of function, are a matter of debate. The abnormal gait patterns among this population are a mixture of primary (disordered motor control), secondary (musculo-skeletal deformities), and tertiary abnormalities **[19]**.

The main finding of this study was that, there was a negative weak correlation between the FPI-6 total score and the walking speed (m/sec), cadence (cycle/sec), the time on the affected side (%) and ambulation index. Positive relation was found between the step length of the affected side (m) and the FPI-6 total score. Moreover, a significant relation was recorded between the FPI-6 total score and the total distance (m) and the coefficient of variation

Our results could be attributed to the characteristics of the study sample that were diagnosed as hemiparetic CP. According to the GMFCS, they were at level I and II while the spasticity level grade was 1 and $1^+$ according to MAS. Based on the previous criteria, the children participated in the current study were mild hemiparetic CP with mild impairments in motor function and gait. This may explain the significant relation between foot posture and only the total distance (m) and the coefficient of variation which represent the amount of variation occurring between footfalls.

The findings of this study are supported by previous studies which stated that, most of the children with spastic hemiparetic CP have the ability to walk with minimal restrictions, although some motor activities are compromised, particularly for using stairs and traveling on uneven terrain. According to these concepts, patients with spastic hemiparesis are ambulatory and are placed at levels I and II of the GMFCS, referring to independent walking with difficulty in running, jumping or walking on uneven terrain, with or without use of orthoses **[20-23]**.

Additionally, **Kerr and Selber [24] and Bax et al. [25]** reported that, limitations in activity and motor function that are most affected and with alterations in gait patterns that depended on the site of injury and type and severity of brain damage.

The results may also be attributed to the assessment procedure of foot posture which intended to assess the static foot posture by the FPI-6. It has been suggested as a fast, cheap and simple method of visually classifying foot postures without any possible risks when compared to other assessment modalities as radiography. The foot is classified as pronated, supinated or normal based upon the FPI-6 six different visual foot posture criteria. The FPI has criterion validity with moderate to good intra and inter-rater reliability **[26]**. This comes in agreement with previous studied which stated that, there are variety of assessment tools exist for quantifying foot posture and function, including radiographic imaging, footprint measurements, and dynamic laboratory analyses **[27]**. The gold-standard tool remains the laboratory gait analysis, however to produce high-quality objective analysis are expensive, and the assessment process of acquiring the data can be overly time-consuming for routine patient assessment. Similarly, Radiographic imaging is similarly demanding and cannot be justified for routine screening because of the risks associated with exposing subjects to ionizing radiation. As an objective clinical alternative method based on footprints are sometimes used, and while these have proven relatively reliable, the relationship between these measures and dynamic function is variable **[16]**. The FPI being reported to be more reliable than other indices to estimate the foot dynamic function. It has been shown to have both a weak **[28, 29]** as well as a strong relationship to dynamic foot function **[16]**.

According to the selection criteria of the participants, children were excluded if they had severe/fixed deformities of the lower limbs. The results of the current study revealed that 30 children representing 57.7% of the total sample had neutral feet according to the FPI-6 total score. While, 21 children representing 40.4% showed pronated feet. Only one child had supinated foot (1.9 %). These results may explain the results of the current study. These results indicate that, children with mild hemiparesis show mild foot and ankle impairments which are believed to have no significant effect on gait parameters.

The statistical analysis of the current study showed significant relation between the FPI and total distance (m) and the coefficient of variation while non-significant relation was recorded regarding the walking speed (m/sec), cadence (cycle/sec), the time on the affected side (%), step length of the affected side (m) and ambulation index. This could be attributed the use of the FPI-6 for assessment of static foot posture which is believed to predict the dynamic foot function during gait. This matches the opinion of **Redmond et al. [16]** who mentioned that, the FPI component scores can be aggregated to cover multiple planes and anatomical segments and show strong relationship to dynamic foot function.

Our results come in consistent with, **Redmond and colleagues [16]** who mentioned that, the FPI-6 total score can be used to predict 41% of dynamic ankle movement in the frontal plane, particularly during the midstance phase. Furthermore, the results of a study conducted more recently by **Chuter [29]** who reported that higher FPI-6 total score scores (i.e. more planus or pronated foot posture) showed a significant positive relationship ($r = 0.92$, $p < 0.05$) with peak rearfoot eversion. According to this study, the FPI total score may be used to predict 85% of maximum rearfoot eversion. Moreover, **Buldt et al. [30]** mentioned that different foot postures are associated with differences in the dynamic situations of the foot when walking and running rather than in the static position

**Buldt et al. [31]** stated, scoring of the FPI score is strongly influenced by soft tissue morphology and therefore provides a relatively limited insight into the underlying bony structure of the medial longitudinal arch. It provides limited explanation of dynamic foot motion during walking as there are extrinsic force demands of gait, intrinsic foot structure, and neuromuscular control can influence foot motion during gait.

Our results come in disagreement with **Paterson et al. [32]** who found weak correlation between static measures that have limited dynamic prediction ability of foot posture and rearfoot or midfoot kinematics, suggesting that the FPI may not be an accurate tool for representation of rearfoot or midfoot motion when walking regardless of the employed measurement technique. They suggested that frontal plane rearfoot and midfoot movement is better explained by factors other than static foot posture. In the same line, **Scharfbillig et al. [33]** reported lower associations ($\rho$<0. 06) between individual FPI items and relevant radiographic measures in healthy young adults, as well as the poor sensitivity of the FPI for detecting small changes in the dynamic foot posture.

Our results contradict with **Mentiplay et al. [34]** who investigated the foot posture using a low-cost depth commercially available camera, the Microsoft Kinect™ or 3D motion analysis system. They found that greater intra-rater reliability and validity of the Microsoft Kinect™ and 3D motion analysis system in assessment of dynamic foot posture when compared with visual assessment of foot posture that only assess the static foot position.

**Study limitations**

Only children with limited diagnoses and severity were included. It will be favorable to the upcoming studies to consider objective sophisticated evaluation methods of the dynamic foot posture and its effect on gait.

## VI. Conclusion

Upon the findings of the present study, it could be concluded that static foot posture doesn't correlate with the gait parameters in mild spastic CP children. The FPI-6 may not be accurate indicator to identify the effect or relation of foot posture to gait parameters in mildly affected spastic hemiplegic children.

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**Conflicts of interest**

No potential conflict of interest relevant to this study was reported.

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**Box 1. the FPI-6 clinical criteria**

1. Talar head palpation. The head of the talus is palpated on the medial and lateral side of the anterior aspect of the ankle, and the degree of medial or lateral prominence is documented. In a pronated foot, the talar head will be more palpable on the medial side, whereas in a supinated foot, the talar head will be more palpable on the lateral side.
2. Supralateral and infralateral malleolar curvature. The curves above and below the lateral malleolus are observed. In a pronated foot, the curve below the malleolus will be more acute than the curve above due to the valgus orientation of the foot, and the opposite is observed in the supinated foot.
3. Frontal plane alignment of the calcaneus. The posterior aspect of the calcaneus is visualized and degree of eversion/inversion of the heel is documented. A pronated foot will demonstrate a more everted heel position and a supinated foot will exhibit a more inverted heel position.
4. Prominence in the region of the talonavicular joint. The skin immediately superficial to the talonavicular joint is observed. In a pronated foot, the talonavicular joint will be more prominent, whereas in a supinated foot the talonavicular area will be indented.
5. Congruence of the medial longitudinal arch. The height and congruence of the medial arch are observed. A pronated foot will demonstrate a low arch with flattening in the central portion, whereas a supinated foot will demonstrate a higher arch acutely angled towards the posterior portion.
6. Abduction/adduction of the forefoot on the rearfoot. When viewed from directly behind, a pronated foot will result in more of the forefoot being visible on the lateral side due to forefoot abduction, whereas a supinated foot will result in more of the forefoot being visible on the medial side due to forefoot adduction.

**Box 2. The Biodex Gait Trainer 2™ parameters**

1. Total Distance (meter): This is the total distance traveled by the belt, which is in essence the distance traveled by the patient.
2. Average Walking Speed (meter/second): Normative values have been established and are dependent on age and sex. The norms are expressed next to the real time value.
3. Average Step Cycle (cycle/second): This is calculated by taking an average for the step cycles during the exercise bout.
4. Average Step Length (meter): This number is calculated by taking an average for all of the step lengths.
5. Coefficient of Variance: This is calculated as the amount of variation occurring between footfalls.
6. RT/LT time distribution: This is the actual time spent on the mentioned limb. The time spent on each limb should be equally distributed between right and left. Should they be different, the patient is spending more time on one leg than the other.
7. Ambulation Index: This is a composite score relative to 100 based on foot-to-foot time distribution ratio and average step cycle. The goal is 100.

**Table 1. Patient demographics and clinical data**

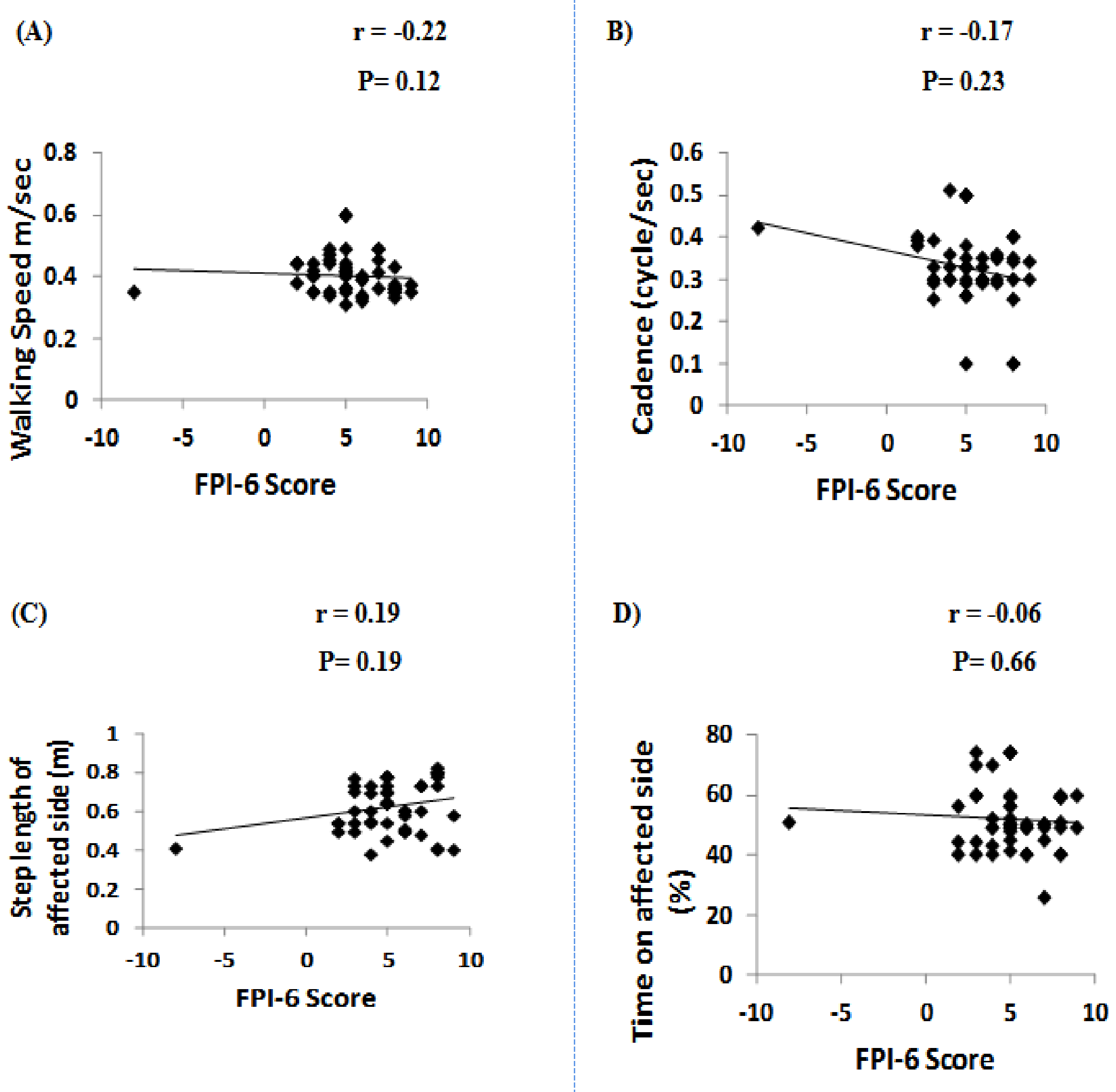
| | Mean±SD | N (%) |
|---|---|---|
| Age (year) | 8.4 ± 1.2 | |
| Height (meter) | 1.2 ± 0.1 | |
| Weight (kilogram) | 26.4 ± 4.4 | |
| Sex | | |
| · Girls | | 25(48.1) |
| · Boys | | 27(51.9) |
| Affected Side | | |
| · Right | | 26(50) |
| · Left | | 26 (50) |
| Gait parameters | | |
| · Walking speed (meter/second) | 0.40 ± 0.1 | |
| · Cadence (cycle/second) | 0.33 ± 0.1 | |
| · Step length of affected side (meter) | 0.63 ± 0.1 | |
| · Time on affected side (%) | 52 ± 10.3 | |
| · Ambulation index | 45 ± 13.7 | |
| · Total distance (meter) | 82.2 ± 21.6 | |
| · Coefficient of variation | 26.6 ± 9.9 | |
| FPI-6 | | |
| · Total score | 5.2 ± 2.6 | |
| · Neutral feet | | 30 (57.7) |
| · Pronated foot | | 21 (40.4) |
| · Supinated feet | | 1 (1.9) |

SD: Standard deviation; FPI: Foot posture index.

**Table 2. Correlations of foot posture with spatio-temporal gait parameters**

| Spatio-temporal gait parameters | FPI-6 | |
|---|---|---|
| | *r* | *P* |
| Walking Speed (meter/second) | -0.22 | 0.12 |
| Cadence (cycle/second) | -0.17 | 0.23 |
| Step length of affected side (meter) | 0.19 | 0.19 |
| Time on affected side (%) | - 0.06 | 0.66 |
| Ambulation index | -0.25 | 0.06 |
| Total distance (meter) | -0.29 | 0.03* |
| Coefficient of variation | 0.32 | 0.02* |

FPI: Foot posture index; r: Person correlation coefficient; P: Probability, * Sig. correlation



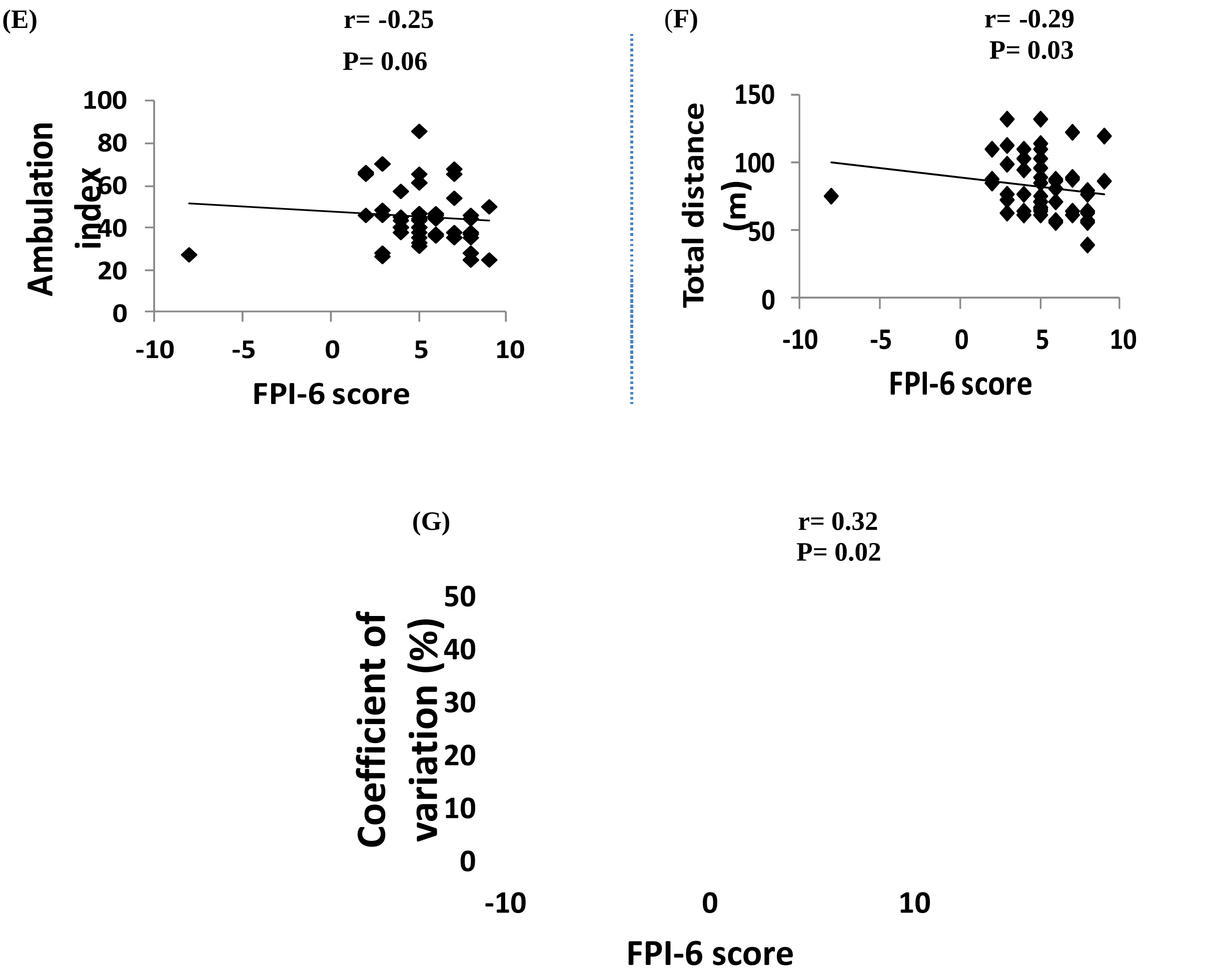



**Figure 1:** weak Correlations were found between the total FPI-6 score and walking speed (m/sec) [A], cadence (cycle/sec) [B], step length (m) [C], time on affected side (%) [D], and Ambulation index [E]. Significant fair Correlations were found between the total FPI-6 score and Total distance [F] and Coefficient of variation [G] in children with hemiplegic CP.

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