Clinical Research

Analysis of Physiological Gait Pattern in Children Without the Influence of Footwear

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Abstract: *In the literature, there have been several studies that have analyzed and explained the characteristics of physiological gait in association with pathologies; however, finding information about normal gait pattern while barefoot is difficult. This study focuses on the differences in the barefoot gait between children and adolescents. A total of 320 healthy children and adolescent were recruited and divided into groups according to age: G1 (1-6 years), G2 (7-10 years), G3 (>11 years). Data were collected using a dynamometric platform and analyzed using SPSS software. This study's findings indicate that there are differences in the swing, stance, load, and single support phases of gait. To our knowledge, this is the first study to present the values of standardized data on barefoot gait pattern in children aged from 2 to 10 years.*

Levels of Evidence: *Diagnostic, Level IV: Case series*

Keywords: physiological gait pattern; analysis; gait while barefoot; children

The human gait refers to locomotion achieved through the swinging of the lower limbs. This movement is composed of 2 phases: single and double support. During the gait cycle there is always contact with the ground, differing from movements like running and springing.[1]

During the first years of childhood, children experiment with their neuromuscular and skeletal systems until there is a full integration of the movement. It is not clear whether walking is an innate process or a learned process. According to McGraw and Andre Thomas, gait is an automatic reflex or an innate process that is developed through trial and error.[1,2] Other researchers describe gait as a learned process with factors such as environment, weight, and size affecting the development of the individual gait characteristics.[2-5]

> "It is not clear whether walking is an innate process or a learned process."

Between 13 and 15 months of age, children try to master walking although their pattern is irregular und unstable.[6,7] During the second year of life, a child's gait has a valgus pattern that it is very pronounced; however, it is corrected around the third year of age.[8] Some researchers argue that a child develops an adult gait pattern around 5 to 7 years of age,[6,7] while others claim that adult gait actually develops around 7 to 8 years of age.[9] Factors such as the length of the step change during the childhood years. When a child is between 8 and 10 years old, this length is 3 times longer compared with a 1-year-old child. This increase in step length is due to the fact that the lower limbs are growing.[7,8] At approximately 15 years of age, the child reaches the gait values of adulthood.[9,10]

Gait is very important for the psychomotor development as it allows the child to move around space, increasing their visual field and ability to manipulate objects.[11,12] Several researchers have described the changes in plantar pressures and load distribution among people with various gait patterns; however, there have not been many studies focusing on people with normal gait pattern while barefoot.[13]

This study aims to standardize the physiological parameters during the gait pattern in children with normal gait while barefoot. The standardization of different phases of the gait cycle will help analyze the efficiency of

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orthopaedic devices for children with abnormal gait pattern and help design an optimal therapeutic treatment.

Methods

Participants and Procedures

A total of 320 participants between the ages of 2 and 21 years were recruited for this study. They were invited to take part in the study by a random approach—on the street, in schools, and in daycare centers. The exclusion criteria were neuromuscular diseases, pains, surgical procedures, foot deformities, and abnormal mass index.[14] There was no delay in developmental motor skills found among the participants.

A dynamometric platform and Zebris-Win FDM software were used for data collection and analysis. Each participant was asked to walk barefoot on the platform 3 times with each foot to collect data. Each participant had 2 examiners conducting an interview and examination. The 5 examiners involved were trained and supervised by the first author to ensure reliability during the data collection.

Each participant was pretested and gave written consent prior to the examination. The participants were asked to place themselves at the end of a platform and to walk on the platform while data were collected.

Comparisons were made between the stance phase and its subphases (load response, support, and preswing phase) and the swing phase. Parameters such as forefoot forces and internal rotation were also analyzed.

Participants were divided into 3 groups according to their age: G1 from 1 to 6 years (n = 92), G2 from 7 to 10 years (n = 72), and G3 equal to or older than 11 years (n = 156). The distribution according to their age was as follows G1, 41.88%; G2, 28.75%; and G3, 29.37%.

Data Analysis

Data analysis was performed using "Statistical Package for the Social Sciences" (SPSS version 18.0).

Figure 1.

Swing phase: statistical results for the 3 groups.

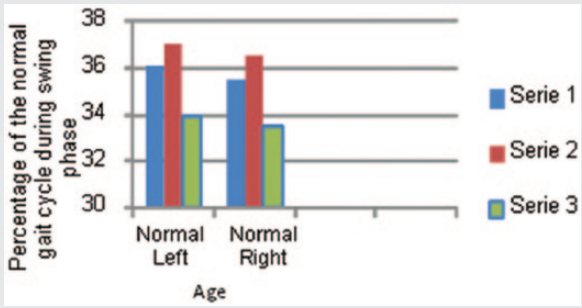


Table 1.

Swing Phase: Statistical Data and Results for the 3 Groups.[a]

Swing Phase	Median	95% CI	SD	Interquartile Range
G1, <6 y				
Left foot	36.26	±0.81	4.86	5.2
Right foot	35.88	±0.73	4.39	4.9
G2, 7-10 y				
Left foot	37.31	±0.8	3.9	4.2
Right foot	37.01	±0.71	3.48	3.75
G3, ≥7 y				
Left foot	35.50	±0.62	4.35	5.3
Right foot	34.49	±0.47	3.29	4.8

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3.

Results

Stance Phase and Swing Phase

During physiological gait, there are 2 phases clearly defined: the swing phase lasting around 40% of the total cycle (Figure 1, Table 1), and the stance phase lasting about 60% of the normal gait cycle (Figure 2, Table 2). For this study, during the stance phase, the values (G1, 36.26%-35.88%; G2, 37.31%-37.01%; G3, 35.50%-34.49%) obtained were less than 40%, and during the swing phase, the values obtained were greater than 60% for the 3 groups (G1, 63.4%-63.88%; G2, 62.69%-62.99%; G3, 64.50%-65.51%).

Load Phase, Single Support Phase, and Preswing Phase

The stance phase is divided into 3 subphases: load response that corresponds to 15%; single support that correspond to 30%; and preswing that correspond to 15% of the whole gait cycle. Figures 3, 4, and 5 and Tables 3, 4, and 5 compare the different stance subphases, respectively, in the 3 test groups.

Figure 2.

Stance phase: statistical results for the 3 groups.

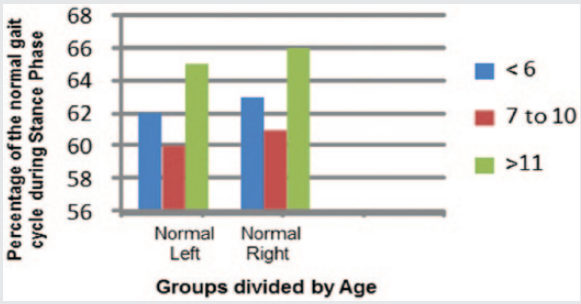


Table 2.

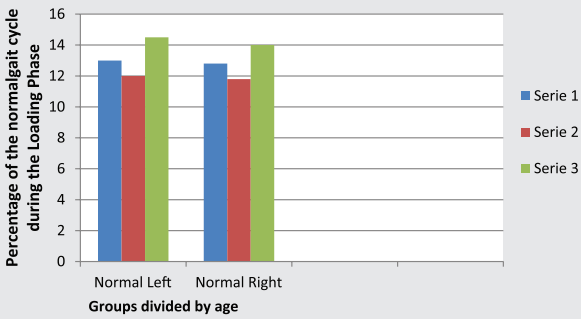
Stance Phase: Statistical Data and Results for the 3 Groups.[a]

Stance Phase	Median	95% CI	SD	Interquartile Range
G1, < 6y				
Left foot	63.4	±1.02	6.08	5.2
Right foot	63.88	±0.87	5.17	5
G2, 7-10 y				
Left foot	62.69	±0.8	3.9	4.2
Right foot	62.99	±0.71	3.48	3.75
G3, ≥11 y				
Left foot	64.50	±0.62	4.35	5.3
Right foot	65.51	±0.47	3.29	4.08

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3.

Figure 3.

Loading phase.



Results for the load phase show a lower value for the groups G1 and G2 when compared with group G3 or adults (Figure 3, Table 3).

In contrast, the single support phase values were less than 40% for all the groups. The G3 values are much lower than the other 2 groups; however, the values are still greater than 30% (Figure 4, Table 4).

The preswing phase values are lower for the groups G1 and G2; however, G3 reaches values closer to the gait values in adulthood (left foot 21.9, right foot 20.3) (Figure 5, Table 5).

Forefoot Force

During the different phases of the gait cycle, one of the most important parameters is the forefoot force. In this study, the forefoot force was found to progressively increase (Figure 6, Table 6).

Foot Rotation

Figure 7 and Table 7 show that individuals in G3 tend to increase the internal rotation when compared with those in the other 2 groups, indicating that the foot changes from external rotation to neutral position with age. Therefore, there is an internal rotation of the foot.

Discussion

The walking pattern is a learned process that is determined by several environmental factors.[2] The child develops independent walking around 12 to 15 months, although the gait is initially unstable. During the second year, the child gains the first independent steps although with balance difficulties.[3,6,15] In addition, during the first years of childhood, children establish the gait, develop the ability to walk longer distance with fewer falls, and the support base begins to shrink. Toward 5 to 7 years, the gait evolves and begins to resemble the adult gait.[9,10]

Some literature makes the claim that children's gait becomes similar to the

Figure 4.

Single support phase.

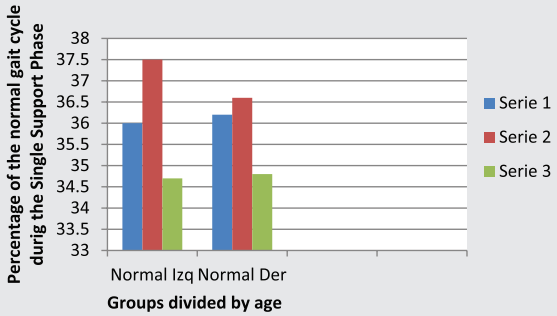


Figure 5.

Preswing phase.

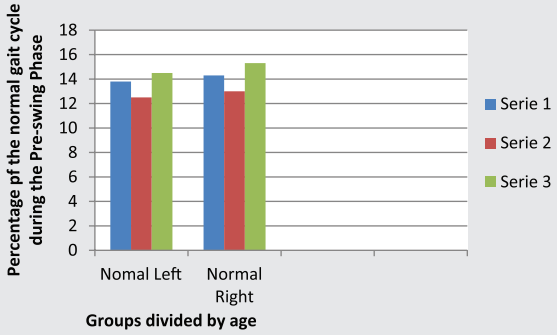


Table 3.

Load Phase: Statistical Data and Results for the 3 Groups.[a]

Load Phase	Median	95% CI	SD	Interquartile Range
G1, <6 y				
Left foot	13.12	±0.56	3.36	4.4
Right foot	12.88	±0.61	3.62	4.3
G2, 7-10 y				
Left foot	12.22	±0.65	3.17	3.65
Right foot	11.95	±0.5	2.44	2.78
G3, ≥11 y				
Left foot	14.23	±0.42	2.95	3.3
Right foot	14.08	±0.4	2.84	3.28

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3.

adult's gait around 7 years of age.[9,10] In this study, it was observed that the physiological gait is still changing until the age of 10 or 11 years. After the age of 11 years, the gait pattern becomes more stable and fewer changes are observed. It is important to highlight that, unlike the conditions in this study, in literature the gait analysis was done while the participants were wearing shoes.

Swing Phase

In our study, we have clearly defined the gait cycle phases and their main physiological characteristic,[16] along with a comparison between different age groups. It was found that during the swing phase, the gait values in children are lower than those of adults.

Stance Phase

As the values during the swing phase decreased, the stance phase values increased to more than 60%. Group G3 had the larger stance phase (64.50 left foot, 64.51 right foot), followed by G1 (63.4 left foot, 63.88 right foot), and finally, G2 (62.69 left foot, 62.99 right foot).

Load Response Phase

During the load response phase, the values found were less than 15% for the 3 different groups: G1 (13.12 left foot, 12.88 right foot); G2 (12.22 left foot, 11.85 right foot); and G3 (14.23 left foot, 14.08 right foot).

For the single support phase, the values increased for the three groups G1 (36.27 left foot, 36.46 right foot) and G2 (37.56 left foot, 36.81 right foot) the values obtained were higher than these of G3 (35.10 left foot, 35.95 right foot). With the results obtained in this study, it is evident that there is a change of the values on the stance phase, and the support phase. Those results are representing the unstable gait that the child has during the first year of age. The ability to walk changes with the time as the child's motor skills develop and the gait

Table 4.

Single Support Phase: Statistical Data and Results for the 3 Groups.

Single Support Phase	Median	95% CI	SD	Interquartile Range
G1, <6 y				
Left foot	36.27	±0.93	4.81	5.4
Right foot	36.46	±1.04	5	5.9
G2, 7-10 y				
Left foot	37.56	±0.7	2.59	3.85
Right foot	36.81	±1.09	3.67	3.55
≥11 y				
Left foot	35.10	±0.6	3.43	4.28
Right foot	35.95	±1.17	4.94	4.35

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3.

Table 5.

Preswing Phase: Statistical Data and Results for the 3 Groups.[a]

Preswing Phase	Median	95% CI	SD	Interquartile Range
G1, <6 y				
Left foot	13.83	±0.78	4.02	4.6
Right foot	14.52	±0.83	3.99	4.38
G2, 7-10 y				
Left foot	12.44	±0.75	2.76	2.88
Right foot	13.24	±1.15	3.9	4.28
G3, ≥11 y				
Left foot	14.63	±0.54	3.07	3.28
Right foot	15.45	±0.85	3.58	5.3

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3.

becomes slower, more controlled, and more stable. In literature, it was found that during the first childhood years, the gait patterns are very unstable and imbalanced.[6,7]

During the preswing phase, the values are also lower than the values from the adults (21.9 left foot, 20.3 right foot) for group G1 (13.83 left foot, 14.52 right foot) and group G2 (12.44 left foot, 13.24 right foot). The values for G3 are closer to the values expected during adulthood (14.83 left foot, 15.45 right foot).

Forefoot Forces

Some authors have reported that plantar pressures are lower in children than in adults because of the fact that children weigh less than adults.[10] These authors explain that the knee valgus of children places greater pressure on the

Figure 6.

Forefoot force (N): the force on the dynamometric platform for the 3 groups.

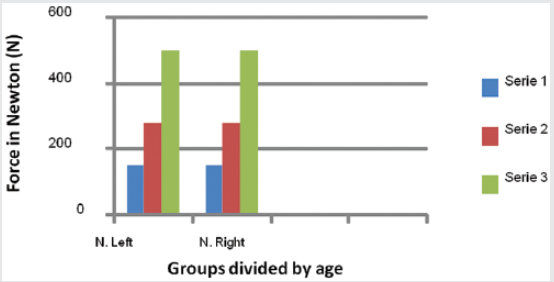


Table 6.

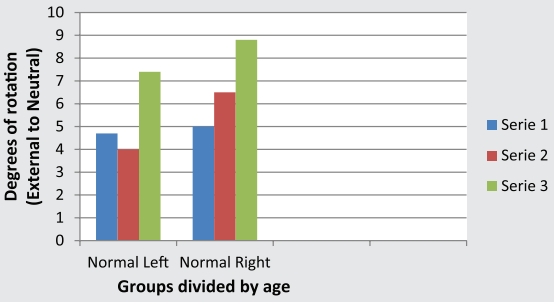
Forefoot Force (N): Statistical Data and the Force on the Dynamometric Platform for the 3 Groups.[a]

Forefoot Force	Median	95% CI	SD	Interquartile Range
G1, <6 y				
Left foot	170.13	±16.42	96.6	64.1
Right foot	170.76	±16.37	96.34	70.2
G2, 7-10 y				
Left foot	295.47	±15.29	74.4	86.8
Right foot	295.75	±16.15	78.61	109
G3, ≥11 y				
Left foot	520.02	±21.85	153.7	202.1
Right foot	519.85	±22.91	161.12	219.25

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3. The data were measured in newton.

Figure 7.

Internal rotation (degrees) for the 3 groups.



head of the first metatarsal resulting in a foot pronation. Around 6 years of age, the child's pressure distribution is similar to adult's as the plantar arch is properly shaped. Nevertheless, the process of ossification of the child's foot is more immature than the adult's so there are still differences.[10,13,17] In this study, it was found that the forefoot forces increase with age (Figure 6). As others researchers explain, there is a directly proportional increase of the forefoot forces with age.

Foot Rotation

It was determined that there is an internal rotation that increases with age. It was identified that during the first childhood years, the feet are externally rotated. When children start walking, they exhibit an external rotation pattern on the feet that helps them keep balance. With the development of the gait, the foot rotates from external rotation to neutral. Therefore, there is an inward foot rotation. No literature was found that describes this phenomenon (Figure 7).

Unfortunately, the dynamometric platform used during this study was too short to measure the length of the step in the participants. Using a longer platform in future studies is recommended to better measure how the length of the step correlates with age. Children at age 10 years have a step length 4 times longer than the first years and children at 8 years have a step 3 times longer than the first years.[7,8] Factors such as longer limbs and joint ankle changes contribute to this change.

Conclusion

This study found that there are changes between the adults and the child gait patterns. These changes become evident when observing the stance and swing gait phases of subjects at different ages. During the swing phase, it was found that the values for the 3 groups are lower, while the values during the stance phase and specifically during the load

Table 7.

Internal Rotation (Degrees) for the 3 Groups.[a]

Internal Rotation	Median	95% CI	SD	Interquartile Range
G1, <6 y				
Left foot	5.12	±1.40	8.35	10.7
Right foot	5.29	±1.40	8.35	10.6
G2, 7-10 y				
Left foot	4.26	±1.32	6.45	7.03
Right foot	6.72	±1.42	6.97	8.2
G3, ≥11 y				
Left foot	6.09	±1.03	7.23	10.75
Right foot	7.68	±0.85	6	7.7

[a]Average loadings of left forefoot and right forefoot differentiated into age groups G1, G2, and G3.

response phase are higher compared with an adult's values.

It was also found that there are gait changes that occur between 6 and 7 years of age and between 10 and 11 years of age. After the age of 11 years, the gait pattern stabilizes and resembles the one of adulthood.

This study shows the first values during a normal gait for children with normal gait conditions and without the influence of footwear. Knowing these values will help compare gait patterns in normal conditions and abnormal conditions without the influence of shoes. This information will also help assess the orthopaedic and therapeutic treatments for abnormal conditions since having the standard values in children with healthy conditions will be useful to determine gait abnormalities or alterations. FAS

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