ORIGINAL PAPER

Physiotherapy Quarterly (ISSN 2544-4395)
2022, 30(3), 7–12


# Effect of antigravity moon shoes on gait cycle in children with diplegic cerebral palsy

DOI: https://doi.org/10.5114/pq.2022.116446

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**Abstract**

**Introduction.** The study aimed to evaluate the effect of antigravity moon shoes on the values of stance and swing phases of the gait cycle in children with diplegia.
**Methods.** The study involved 30 children with spastic diplegia, aged 6–8 years, of both genders. They were randomly divided into 2 groups: A and B. All children were evaluated before and after 4 successive months of a rehabilitation program with 2-dimension gait analysis for measuring step lengths and values of stance and swing phases for both lower limbs. Both groups received a designed program which included stretching exercises for tight flexors of the lower limbs, progressive resisted exercises for extensors, and standing and weight shifting exercises. In addition, classical gait training was applied in group A and gait training with antigravity moon shoes in group B. Mann-Whitney U test served to assess differences in means of step length between the groups. Wilcoxon signed rank test was used to evaluate differences in means of step length and values of stance and swing phases during gait cycles.
**Results.** Post-treatment results revealed a decrease in step lengths and stance phase values, as well as increased values of swing phase for both groups. The changes were more significant in group B.
**Conclusions.** Antigravity moon shoes are a new idea to improve gait pattern in children with diplegia by decreasing stance time and increasing swing time in the gait cycle.
**Key words:** moon shoes (antigravity shoes), diplegic cerebral palsy, gait

## Introduction

Depending on the level of involvement, children with cerebral palsy present different gait deviations, including increased hip flexion, increased knee flexion, decreased ankle dorsiflexion, increased knee extensor moments, and increased hip extensor moments during stance phase with decreased time of swing phase [1, 2]. Crouched gait posture tends to be the area of greatest concern for diplegic children. Increased lower limb joint flexion as a result of weak extensor and tight flexor groups of both lower extremities is more obvious during ambulation, leading to poor endurance and decreased functional mobility at home and within the community. Children with diplegia generally have normal cognition but may experience some social and emotional difficulties. They often require assistive devices such as walkers or crutches for long-distance mobility [3]. During the gait cycle, hip and knee joints play a major role in providing dynamic and static stabilities. Abnormal muscle tension results in toe-in and crouch gait, which increases instability during ambulation [4]. In diplegic children, those patterns decrease the base of support in the stance phase and increase the leg crossing in the swinging phase of gait, which may raise the risk of falling [5]. The quality of gait is decreased owing to imbalance in muscle action between lower extremity flexors and extensors, which tends to increase the stability time of the gait cycle in relation to the less-stability phase time to avoid falling [6].

Gait analysis offers a more accurate and objective assessment of gait than other conventional methods, such as clinical examination and visual observation alone [7]. A 2-dimension (2D) technique (with a single video camera) is used to perform lower limb kinematic analysis. It provides estimation of spatiotemporal parameters, as well as unilateral joint kinematics of hip, knee, and ankle in the sagittal plane. The 2D technique was found suitable for clinical use [8].

One of the most common rehabilitation goals is to improve the mobility and walking abilities which assist in daily activities and social engagement [9]. Although traditional approaches for physical therapy rehabilitation are important steps of cerebral palsy children management, it should also prepare them for independent adult life. To achieve this goal, different adaptive equipment to correct malalignment and assistive devices to aid ambulation are used [10]. Antigravity shoes (moon shoes) are utilized for working on balance, posture, core strength, gluteal region strength, stretching out calves, and overall leg strength. In physiotherapy, antigravity shoes are applied to target various points, specific to each child [11], as integration of vision, proprioception, and vestibular information is the key to functional locomotion. Vision and proprioceptive sensory feedback control the motor output, and the vestibular system regulates antigravity muscle tone of the lower leg at the same side to maintain an upright posture during the gait [12].

The fundamental parameters that organize gait time and space are the spatiotemporal parameters, which include step and cycle time, step length and width, stance/swing phase duration, and the double support. Asymmetry of gait pattern and efficacy of the rehabilitation treatment program can be objectively assessed by one or more of these parameters. Inadequate step length, stance time, and cadence are common features related to less efficient gait and low community participation [13].

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Received: 18.02.2021
Accepted: 23.07.2021

*Citation*: Ibrahim NM, Attia RG, El-Sayed Shoukry K. Effect of antigravity moon shoes on gait cycle in children with diplegic cerebral palsy. Physiother Quart. 2022;30(3):7–12; doi: https://doi.org/10.5114/pq.2022.116446.

So, the aim of this study was to evaluate the effect of antigravity moon shoes on changing the percentage of stance and swing phases time during gait cycles as a result of step length modification in children with spastic diplegia as a major element for increasing the efficiency of gait in those children.

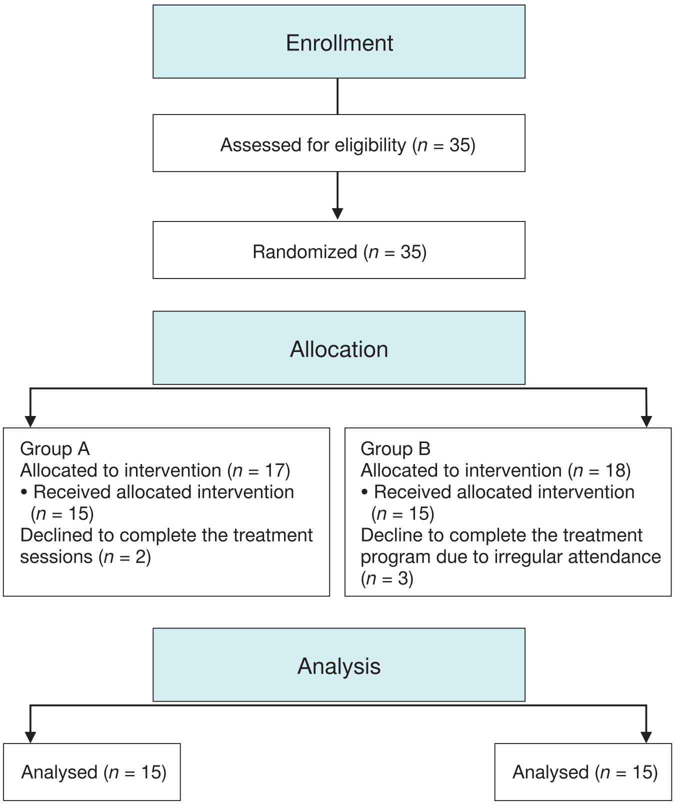

Figure 1. Participants' flow chart

## Subjects and methods

### Study design and participants

A randomized controlled trial was conducted between 2018 and 2020. The treatment was held at the paediatric outpatient clinic of the Faculty of Physical Therapy, Cairo University. Children were enrolled into the study if they met the following criteria: diagnosed cerebral palsy of spastic diplegia; age of 6–8 years; grade 1+ spasticity of hip, knee flexors and 1 for ankle plantar flexors according to the Modified Ashworth Scale [14]. They had difficulty walking outdoor or they needed assistance (level II or III) according to the Gross Motor Function Classification System [15]. The children were able to follow simple instructions given to them during assessment or treatment sessions. Participants were excluded if they had severe sensory impairment, uncontrolled epileptic fits, or an orthopaedic surgical intervention or Botox injection in the lower extremities within the preceding 6 months.

### Sample size estimation

Before the commencement of the study, sample size calculation was performed on the basis of the results of a pilot study in 5 subjects. The G*Power statistical software (version 3.1.9.2; Franz Faul, Universität Kiel, Germany) was applied. The appropriate sample size needed was estimated as 30. The calculations involved the values of $\alpha = 0.05$ and $\beta = 0.2$, as well as a large effect size.

### Randomization

A total of 35 participants met the enrolment criteria of the study. They were randomly divided into 2 groups, A and B, by using a computer program (computer-generated random numbers in each group in accordance with the predetermined ratio 1:1). Five of them declined to participate in the treatment sessions regularly before collecting the results after treatment. Finally, the results of treatment of 30 participants, 15 in each group, were statistically analysed. The study flow chart is presented in Figure 1.

### Procedures

#### *Subject selection*

Modified Ashworth Scale was applied. The evaluation of children was held in a relaxed supine position by passively flexing and extending the limb from maximal possible flexion to maximal possible extension. Also, tone was assessed from extension to flexion (increased muscle tone is felt as resistance to passive movement while flexing or extending the limb) [16]. According to Ansari et al. [14], the Modified Ashworth Scale scores from 0, which indicates normal tone, up to 4, when the limb is restricted in flexion or extension position. In this study, the selected children exhibited a slight increase in hip and knee flexor tone (grade 1+) when the limbs moved toward extension with catch followed by minimal resistance throughout the range of ankle dorsiflexion (grade 1).

#### *Evaluation*

A 2D gait analysis was used to measure the values of stance and swing phase for both right and left lower limbs in children of both groups. The assessment was performed with the Tracker Video Analysis and Modelling Tool, free software designed to model and analyse the motion of objects in videos by arranging simple dynamical models directly on the videos and extracting the time of each phase and the acceleration of objects [17]. Increased values of stance phase duration and decreased swing phase values were recorded when participants were evaluated with 2D gait analysis [8].

Adhesive skin markers were applied over the skin on specific sites: at greater trochanter, tibial tuberosity, and lateral malleolus (the markers were placed on both right and left sides) (Figure 2). The children were asked to walk along a 2-m walkway at their free velocity to record the step lengths and the values of stance and swing phases for both lower extremities in a gait cycle. A digital video camera was set up perpendicularly to the centre of the pathway at the distance of 3 m so that it could record the subject in the sagittal plane on the tripod level. This setting ensured that the calibration area covered the whole lower limbs. The videos were recorded in a memory card and then transferred to a laptop to be analysed by the Tracker software [18].

For the analysis of the recorded videos, the Tracker software was used to measure step lengths and the values of stance and swing phases for both lower limbs (starting from foot contact until foot clearance of the same limb). The analyser was selected from the main toolbar to open it, and then the clip found in the tray was dragged and dropped in the window of the analyser to work on it by using the drawing toolbar.

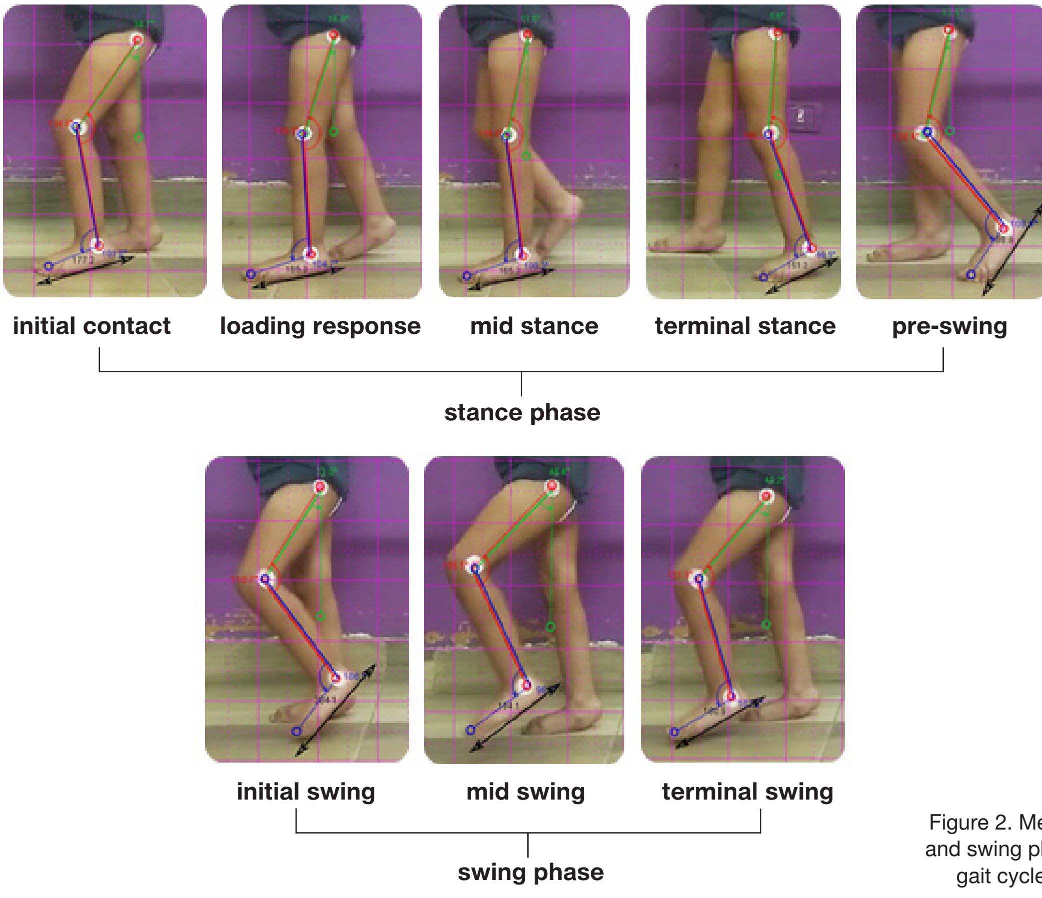


Figure 2. Measurement of stance and swing phases duration during gait cycle for left lower limb

*Intervention*

Physical therapy tools (wedges, rolls, sticks, balance board, and stepper) were used in both groups to apply the exercise program. Antigravity shoes were utilized for gait training in group B (shoes for children fitted with springs as 'mini-trampolines' for feet; they were worn over the children's regular shoes) [19]. The shoes consisted of the base (made of strong light weight plastic), shoe platforms (self-centring, strong, and durable), straps (adjustable to fit up), bands (strong, durable, and adjustable, with elastic tension for great lift and performance), band posts (reinforced and designed to hold the bands tightly), and treads (soft, durable, non-skid material for most surfaces), as shown in Figure 3.

The physical therapy program involved:

1. Traditional exercises for both groups, performed for 30 minutes, that included 5 minutes of stretching exercises for tight muscles of the lower limbs (hip flexors, knee flexors, and calf muscles); progressive resisted exercise for the hip extensors, knee extensors, and ankle dorsiflexors; standing and weight shifting exercise for 10 minutes; and balance exercises for 10 minutes.

2. Classical gait training exercises, performed for 30 minutes, for group A:

a. walking forward, backward, and sideways while holding sticks at both sides (10 minutes);

b. training for gait alone using a stepper (10 minutes);

c. walking through obstacles of different height (10 minutes).

3. For group B, the same gait training exercises as in group A, but with the addition of wearing antigravity shoes.


Figure 3. Antigravity shoes (moon shoes) used for gait training in group B

## Statistical analysis

It was carried out with the SPSS for Windows computer package, version 25.0 (IBM Corp., Armonk, NY, USA). For descriptive statistics, the median and interquartile range ($25^{th}$–$75^{th}$ percentiles) were used for quantitative non-normally distributed variables. For analytic non-parametric statistics, the Mann-Whitney *U* test was applied to assess the differences in means of quantitative variables (step length) between the study and control groups, while the Wilcoxon signed rank test served to evaluate the differences in means of quantitative variables (step length and percentage of stance and swing phases during gait cycles) between pre- and post-intervention values within the same group. The statistical methods were verified, assuming a significance level of $p < 0.05$ and a high significance level of $p < 0.001$.

## Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Committee

Centre, Faculty of Physical Therapy, Cairo University (approval No.: P.T.REC/012/001730). The study has been registered at ClinicalTrials.gov (identifier: NCT04117282).

### Informed consent

Informed consent has been obtained from the parents of all individuals included in this study.

## Results

### General characteristics of participants

The comparison between the groups revealed that there was no significant difference between them in the mean of age, weight, height, or gender ($p < 0.05$). The *p*-value for age was 0.88. The range of the children's weight was 13–25 kg ($p = 0.79$), while the range of their height was 99–127 cm ($p = 0.61$). As for the gender distribution, there were 40% of girls and 60% of boys in group A, and 53.3% of girls and 46.7% of boys in group B. The chi-squared test revealed no significant differences between the groups in sex distribution ($p = 0.71$).

### Measurement of right and left step lengths for both groups before and after treatment

Before treatment, the mean values of both right and left step lengths were matched between the groups. After treatment, their mean values were significantly decreased in group B. Also, within the study group, their mean values were significantly decreased after treatment (Table 1).

Table 1. Right and left step lengths for both groups before and after treatment

| Variables | Before treatment (mean ± *SD*) | After treatment (mean ± *SD*) | *p* |
|---|---|---|---|
| Right step length | | | |
| Group A | 0.66 ± 0.16 | 0.66 ± 0.13 | 0.939 |
| Group B | 0.69 ± 0.2 | 0.53 ± 0.09 | < 0.001* |
| *p* | 0.764 | 0.006* | |
| Left step length | | | |
| Group A | 0.68 ± 0.1 | 0.66 ± 0.09 | 0.422 |
| Group B | 0.73 ± 0.1 | 0.57 ± 0.04 | 0.005* |
| *p* | 0.248 | 0.005* | |

* significance

### Values of stance and swing phase in gait cycle

In group A, the median values of both right and left gait cycles for the stance phase were significantly decreased after treatment, with 9.8% and 6.77% of improvement, respectively. In the swing phase, their values were significantly increased after treatment, with 42.68% and 27.65% of improvement, respectively. In group B, the median values of both right and left gait cycles for the stance phase were significantly decreased after treatment, with 19.98% and 19.52% of improvement, respectively. In the swing phase, their values were significantly increased after treatment, with 85.94% and 86.19% of improvement, respectively (Table 2).

Table 2. Median percentage of stance and swing phases during right and left gait cycles for both groups

| Gait phases | | Right gait cycle (%) (median) (25th–75th IQR) | *p* | Left gait cycle (%) (median) (25th–75th IQR) | *p* |
|---|---|---|---|---|---|
| Group A | | | | | |
| Stance phase | Pre | 81.32 (74.0–86.3) | 0.001* | 80.32 (75.5–89.5) | 0.001* |
| | Post | 73.35 (69.9–80.3) | | 74.88 (71.5–83.5) | |
| Swing phase | Pre | 18.67 (13.7–26.0) | 0.001* | 19.67 (10.5–24.5) | 0.001* |
| | Post | 26.64 (19.7–30.1) | | 25.11 (16.5–28.5) | |
| Group B | | | | | |
| Stance phase | Pre | 81.13 (75.6–90.3) | 0.001* | 81.52 (76.5–88.7) | 0.001* |
| | Post | 64.92 (62.3–67.5) | | 65.60 (63.6–69.5) | |
| Swing phase | Pre | 18.86 (9.7–24.4) | 0.001* | 18.47 (11.3–23.5) | 0.001* |
| | Post | 35.07 (32.5–37.7) | | 34.39 (30.5–36.3) | |

IQR – interquartile range
* significance

## Discussion

The study was conducted to investigate the effect of antigravity moon shoes when added to a gait training program on the change of step lengths and the duration of stance and swing phases during a gait cycle in children with spastic diplegia. For those purposes, 30 children aged 6–8 years were selected; they were randomly divided into 2 groups (A, B) of equal numbers. All participants were evaluated before and after the treatment procedures by using 2D video gait analysis software (Tracker). The treatment program was conducted for 60 minutes per day, 3 times per week, for 4 successive months. Children in group A received a traditional physical therapy exercise program designed for those cases, including the classical gait training, whereas those in group B received the same physical therapy program in addition to gait training with the use of moon shoes. Post-treatment results revealed a significant improvement in group B when compared with group A regarding the duration of gait cycles.

Diplegic children usually have deficits in the selection of appropriate sensory input for postural control that is expected to influence sensory processing and integration. This results in difficulty in the acquisition of mature postural control since the accurate interpretation of sensory cues from the environment is necessary for effective motor planning to occur [20]. Instability in patients with neurological problems during walking can result from inappropriate integration of somatosensory, visual, and vestibular input and/or inability to select the right response to achieve a postural goal during gait [21]. So, promoting motor learning through functional training with multiple sensory stimuli is one of the important goals of physical therapy for children with cerebral palsy. For that purpose, different approaches have been used to improve the selective control and the coordination of muscle contractions during gait [22].

A comparison of the post-treatment measures for both groups revealed a significant alteration in the percentage of stance and swing phases. The decrease of the elongated stance duration with the increase of the swing phase period might be due to an adjustment of the hip flexion-extension angle during the gait cycle. The antigravity shoes with unstable surfaces used for vertical vestibular input (bouncing) work as a mini-trampoline with low up and down swing during walking. Exercise with bouncing is the most effective form of exercise to correct posture and it can improve muscle strength (especially of the trunk muscles), endurance, coordination, and flexibility. This comes in agreement with Romero-Franco et al. [23], who reported that proprioceptive training with unstable platforms improved proprioceptive inputs, which resulted in enhanced balance, trunk stability, and proprioceptive control.

Quality of gait is dependent on suitable sensory input from different systems to allow adequate functional motor output. That was achieved by antigravity shoes, which increase sensory awareness and improve the proprioceptive sensation. This is in line with Tsang et al. [24], who demonstrated that postural control depended on the integration of proprioceptive, vision, and vestibular systems. Of these, the vestibular input is particularly important for adequate motor performance, helping the child to independently participate in daily activities and play and improving their social interaction.

The significant improvement in the post-treatment results for group B in all phases of gait when compared with group A might be attributed to the effect of antigravity shoes, which helped the child to control their lower limb position accurately regarding the range needed in the joints to accomplish the gait. Weight is one of the methods used to strengthen muscles, as moving against weighted shoes and against gravity like during walking helps improve the pattern of gait. This corroborates a view by Magee [25], who stated that muscles had a significant role in the gait cycle. The hip extends the leg during the stance phase and assists in flexing the leg during the swing phase. The hip flexors (primary the iliopsoas muscle) contract to slow extension, the hip extensors (primarily the hamstring muscles) work eccentrically to slow flexion. The functions of the knees during gait are to bear weight, absorb shock, and extend the stride length to allow the foot to move through the swing phase. Gastrocnemius and soleus muscles are significant in controlling the ankle during gait.

The effect of antigravity shoes on the modulation of the time of stance and swing phases of the gait cycle was found through the significant decrease in the stance time in relation to the pre-treatment records, with an increase of the swing time. This reflects the increased stability during gait, as while wearing antigravity shoes, children can move their hips, knees, and ankles more toward the extension. This improves the efficiency of weight bearing and shifting in adequate time, helping them achieve more stability in less time, which was demonstrated by the decreased time of the stance phase. Also, children maintain more balance for a longer period in the non-weight-bearing position to increase the time of the swing phase in the gait cycle. Mittal and Narkeesh [26] stated that the vestibular system played an important role in balance and equilibrium and reinforced the tone of extensor muscles of limbs and trunk, thus being responsible for normal gait.

A child with spastic diplegia who can walk without aids has a reasonably normal muscle function and fairly good selective motor control around the hips, whereas a child who needs balance aids to walk probably does not. Normal gait cycle is dependent on the percentage of stance (nearly 62%) and swing phase (38%). A long stance phase and a short swing phase represent a major gait deficit in diplegic children, potentially causing improper balance during gait. Using antigravity shoes helps the child to control their steps and speed during gait, as reflected by the increased time of the swing phase. This comes in agreement with Gage et al. [27], who stated that most children could walk without assistance but their gait was clumsy and unstable, so they needed to increase their stability during walking; this can be achieved through wearing antigravity shoes.

In group B, the up and down spring movement caused by the antigravity shoes during gait training helped raise the stability and speed of gait by increasing the sensory feedback and the vestibular input to the central nervous system. Usually, children with cerebral palsy have poor sensory feedback, which affects the accuracy of movement execution. Correct functional movement requires a good integration of different types of sensation, such as visual, auditory, and vestibular. This is in line with Schaaf and Roley [28], who reported that children might fear to walk and move owing to poor sensory integration of the surrounding information, especially from the vestibular system. When children were provided with successive and intense vestibular inputs on different swings, they quickly stopped crying and started to respond by trying to keep their head and trunk more erect; in this way, they could gain a better postural control to walk.

## Limitations

This study was limited by other measuring tools to evaluate balance during gait.

## Conclusions

Antigravity shoes help enhance the control of lower limbs by adding weight to improve the proprioceptive and vestibular sense and by decreasing the abnormally raised stance phase. This develops the child's balance and stability in a suitably efficient time.

## Implications for physiotherapy practice

Spastic diplegic children can usually walk either independently or with a moderate to mild assistance. The pattern of gait is the major issue of concern as it frequently affects the quality of life. Therefore, searching for new rehabilitation methods and testing their efficacy in changing life is the main goal in physical therapy practice as it helps apply new ideas with more productivity, less cost, and more interest of patients, especially children.

## Acknowledgements

The authors would like to thank all the children who participated in this study and their parents.

## Disclosure statement

No author has any financial interest or received any financial benefit from this research.

## Conflict of interest

The authors state no conflict of interest.

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