Turk J Phys Med Rehab 2021;67(3):336-343
DOI: 10.5606/tftrd.2021.5175
Available online at www.turkishjournalpmr.com

Original Article

Efficacy of foot-ankle orthosis on balance for children with hemiplegic cerebral palsy: An observational study

Yeliz Bahar-Özdemir[1], Çağrı Ünal-Ulutatar[2], Duygu Karali-Bingül[3], Evrim Karadağ-Saygı[4]

[1]Department of Physical Medicine and Rehabilitation, Hitit University Erol Olcok Training and Research Hospital, Çorum, Turkey
[2]Department of Physical Medicine and Rehabilitation, Sancaktepe Şehit Prof. Dr. Ilhan Varank Training and Research Hospital, Istanbul, Turkey
[3]Department of Physical Medicine and Rehabilitation, Division of Pain Medicine, Istanbul University, Istanbul Faculty of Medicine, Istanbul, Turkey
[4]Department of Physical Medicine and Rehabilitation, Marmara University Faculty of Medicine, Istanbul, Turkey

Received: September 02, 2019 **Accepted:** July 10, 2020 **Published online:** September 01, 2021

ABSTRACT

Objectives: The aim of this study was to investigate the impact of ankle-foot orthoses (AFOs) on the balance and gait and to compare the effects of hinged AFOs with solid AFOs on balance in patients with cerebral palsy (CP).

Patients and methods: Between January 2015 and January 2016, 19 hemiplegic children with CP (11 males, 8 females; mean age: 9.5±2.2 years; range, 6 to 15 years) and 23 sex- and age-matched controls (8 males, 15 females; mean age: 10±1.6 years; range, 6 to 13 years) were included in this study. All patients were using either solid or hinged AFO. Hemiplegic patients were attended to specific tests with orthoses and barefoot. Pediatric Balance Scale (PBS) and Five Times Sit to Stand Test (FTSST) were used for functional evaluation. The quantitative balance was evaluated using the device-assisted balance tests, Limits of Stability (LOS), Walk Across (WA), and Sit to Stand (STS) tests.

Results: The control group had a better functional balance than the CP group (p<0.001 for PBS and p<0.001 for FTSST) and the CP group with AFO had a better balance than the barefoot (p=0.001 for PBS and p=0.009 for FTSST). Children with CP also showed a higher sway velocity in STS (p<0.001) than the control group. In patients with AFO, a decrease in the sway velocity in STS (p=0.037) and an increase in directional control in LOS (p=0.044) were observed, compared to barefoot.

Conclusion: The AFO use offers a significant contribution to the functional balance in CP. Prescribing AFOs are usually required in ambulatory CP patients in combined with a well-designed standard physiotherapy.

Keywords: Balance, hemiplegic cerebral palsy, postural stability.

Cerebral palsy (CP) is a non-progressive, neuromotor disorder affecting the developing fetal or infant brain.[1,2] Spasticity, contracture, impaired sensory perception and conduction, abnormal biomechanical alignment, and impaired posture due to muscle weakness and visual impairment seen in CP are the main causes of impaired balance.[2,3]

The use of orthoses in the CP is complementary to the treatment. The main goals of using orthosis are to improve function, reduce spasticity, prevent contracture development, and to keep the joints in a functional position. The use of ankle-foot orthosis (AFO) provides symmetry in the hip and pelvic movements by increasing the heel strike in the first

Corresponding author: Yeliz Bahar-Özdemir, MD. Hitit Üniversitesi Erol Olcok Eğitim ve Araştırma Hastanesi, Fiziksel Tıp ve Rehabilitasyon Kliniği, 19040 Çorum, Türkiye. e-mail: yelizbahar1@gmail.com

Cite this article as:
Bahar-Özdemir Y, Ünal-Ulutatar Ç, Karali-Bingül D, Karadağ-Saygı E. Efficacy of foot-ankle orthosis on balance for children with hemiplegic cerebral palsy: An observational study. Turk J Phys Med Rehab 2021;67(3):336-343.

contact phase of the walking cycle by correcting the equinus gait in patients with CP, and contributes to walking and balance by increasing knee extension during terminal swing phase.[4-6] Therefore, lower extremity orthoses such as AFOs are often used to reduce or prevent gait disturbances and balance disorders, and contribute to physical mobility in children with ambulatory CP. An effective lower extremity orthosis provides balance during the stance phase, but also avoids the pauses which may occur during the swing phase.[7]

Hemiplegic (unilateral) CP is one of the subgroups seen in CP. Equinus walking is the most common deformity of CP and, 64% of hemiplegic CP patients have equinus deformities.[8] The AFOs have been suggested to prevent this deformity and to provide effective walking. While solid AFOs provide maximum control by restricting movement to plantar flexion and dorsiflexion during the stance and swing phases, hinged AFOs restrict plantar flexion and release the patient's foot motion in the dorsiflexion.[8,9] Hinged AFOs provide more functional walking patterns with the feature of facilitating dorsiflexion, compared to solid AFOs.[10,11]

It has been also well-documented that the use of AFO in the CP improves functionality, prevents ankle deformities, and allows effective walking, as well as obstructing the ankle movements in one or more directions.[12] In addition, afferent proprioception in the muscles, tendons, and other tissues around the ankle is restricted by AFO, further enhancing the need for visual and vestibular inputs to balance the individual.[12] The complete lack of knowledge of the effect of orthoses on balance for these group of patients is due to the fact that studies involving orthostatic balance tests are rarely found in the literature.

In the present study, we aimed to compare children with hemiplegic CP using AFOs (solid or hinged) with each other and with healthy children and to investigate the effect of AFOs on the balance and gait.

PATIENTS AND METHODS

This prospective, single-center, cross-sectional study was conducted at Marmara University School of Medicine, Department of Physical Medicine and Rehabilitation, Pediatric Rehabilitation outpatient clinic between January 2015 and January 2016. A total of 19 patients (11 males, 8 females; mean age: 9.5±2.2 years; range, 6 to 15 years) who were followed in our clinic with the diagnosis of hemiplegic CP and 23 age- and sex-matched healthy children (8 males, 15 females; mean age: 10±1.6 years; range 6 to 13 years) as the control group were included. All children were able to walk independently and stand up without support. All children in the hemiplegic CP group were using solid or hinged AFOs, were eligible for Level 1-2 according to the Gross Motor Function Classification System (GMFCS), and the affected ankle spasticity according to the Ashworth Scale was Level 1-2. Exclusion criteria were as follows: having lower extremity contracture, any orthopedic surgery or botulinum toxin injections within the past six months, conditions disrupting the communication or understanding (attention deficit, mental retardation, etc.), and unwillingness of the child or parents to participate in the study. A written informed consent was obtained from each parent and/or legal guardian of the patient. The study protocol was obtained from the Marmara University School of Medicine Ethics Committee (date, no: 09.2014.0282). The study was conducted in accordance with the principles of the Declaration of Helsinki.

All children with hemiplegic CP were first assessed as barefoot, followed by wearing AFO and subjected to various tests. The orthosis used was a one-sided, semi-rigid polypropylene AFO. The ankle motion of the group using hinged AFO was unrestricted in the dorsiflexion at the malleolus level, and restricted at the 0° plantar flexion, while the solid AFO anchored the ankle in the 0° dorsiflexion to prevent plantar flexion. All evaluated AFOs were performed by a single orthotist in the prosthetic orthosis laboratory of our institution.

The ankle spasticity of hemiplegic CP children was evaluated according to the Ashworth Scale, before the balance tests were applied. All participants were first administered the Pediatric Balance Scale (PBS), which was used as a modification of the 14-items Berg Balance Scale (BBS) and specifically developed for children. The PBS consists of 14 steps and each task is graded from zero to four. The time is recorded with a digital clock. Fifty-six is the maximum total score. The PBS is a reliable test used to evaluate postural control, functional balance, and daily activities in patients with CP.[13] The PBS has been approved for use in children with neuromotor dysfunction.[14] The PBS score is not only used to reveal the balance differences between GMFCS levels, particularly Level 1-3, but also is used in follow-up and treatment planning of these children.[15]

All participants were subjected to the Five Times Sit to Stand Test (FTSST). During the FTSST, the patient was asked to sit down and stand up five times as quickly as possible from a chair suitable for the height of the patient. After every five rounds, the patient was allowed to rest for 1 min and the average duration of three repetitions of the same test was noted. The FTSST correlates with standard functional balance tests used in patients with CP and lower extremity muscle strength and has been shown to be a reliable evaluation criterion.[16]

The NeuroCom Balance Master® (NeuroCom International Inc., FL, USA) computer-assisted device was applied to all participants for quantitative evaluation of the equilibrium. This device consists of a system that processes signals from a fixed 18×60-inch plate which transmits the vertical force applied by the participant through the software program and evaluates the balance and walk of the patient. By measuring the vertical component of the foot pressure center, it yields an objective result about the dynamic and static balance. It is often used to evaluate balance skills in young children.[17] Dynamic balance was assessed using the Limits of Stability (LOS), Sit to Stand (STS), and Walk Across (WA) tests.

In the LOS test, the participant is asked to orient his body in eight directions shown on the monitor by moving his body center of gravity without moving his legs on the plate by holding his arms on his sides. The device measures and records the speed of reaching these targets, the timing, and the distance to reach the target.[18] The reaction time (RT) is the time in sec between the motion start command and the patient's first motion. The movement velocity (MVL) is the average speed during the movement of the center of gravity (deg/sec). The maximum excursion (MXE) is the maximum distance that can be covered during orientation toward the target (%). The end-point excursion (EPE) shows how far the center of gravity has shifted from the center in the axis toward the target in the test (%). The directional control (DCL) compares the amount of movement with the intended direction (toward the target), according to the amount of movement in the other directions (%) (Figure 1a).[19]

With the STS test, the body weight transfer time (sec) and the swing speed (deg/sec) of the center of gravity are measured by analyzing the time from sitting position to standing position (to be held for at least 5 sec), as fast as possible without the support of the upper extremity, and assessed by taking the average of three trials, and the weight transfer time

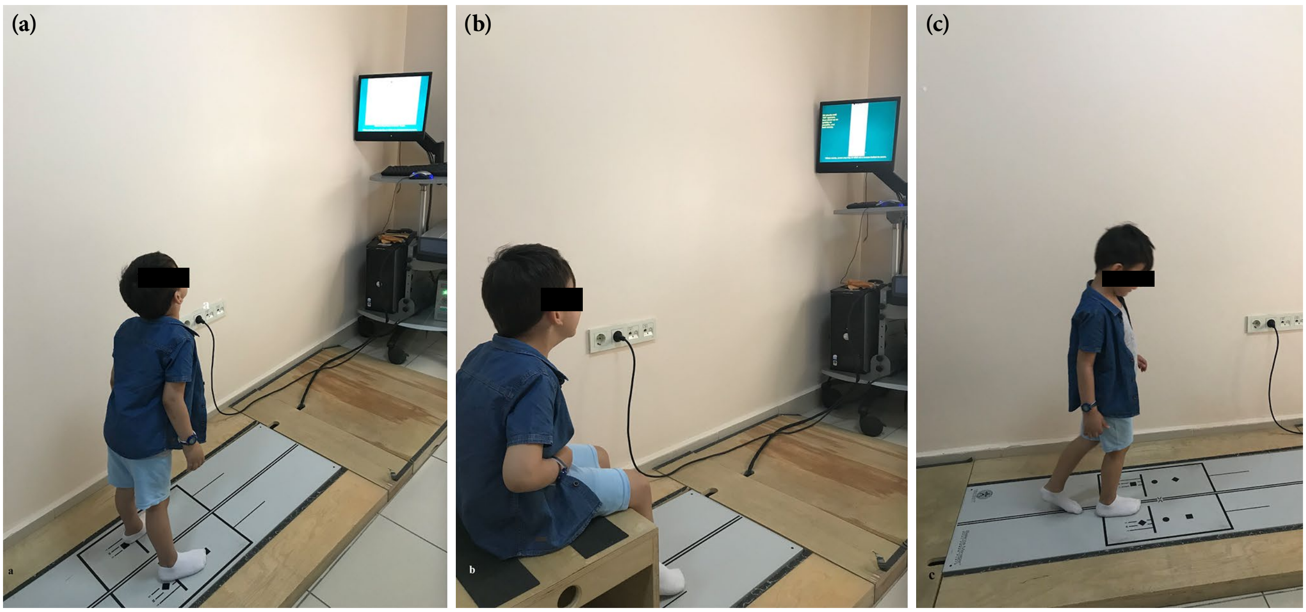

Figure 1. Tests applied on the NeuroCom Balance Master® computer-assisted device. **(a)** A view from the forward orientation sequence in the Limits of Stability test. **(b)** A view from the start of the Sit to Stand test. **(c)** A scene while performing the Walk Across test.

(sec), rising index (%), sway velocity (deg/sec) and DCL are analyzed (Figure 1b).[20]

During the WA test, the participants are asked to walk as fast as possible along the force plate and the average of these evaluations is taken after three repetitions and the walking speed (cm/sec), step length (cm), and step width (cm) are analyzed and recorded.[17] The participants are asked to walk 20 to 30 m before walking on the force plate (Figure 1c).

Statistical analysis

Study power analysis and sample size calculation were performed using the G*Power version 3.1.9 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Depending on the MXE parameter in the LOS test, when the average expected value in the first group (barefoot) was 91.4% (with a standard deviation of 6) and the average expected value in the second group (with AFO) was 86.2% (with a standard deviation of 6.8), based on the study results of Panwalkar and Aruin.[12] To identify the minimum clinically significant difference, 19 patients were required to be recruited to the CP group with 80% power and 5% type 1 error.

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). The histogram and normality plots and Shapiro-Wilk normality test were used for data distribution analysis. Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The independent two groups were compared using the Mann-Whitney U test. For intra-group analyses (CP group with AFO and without AFO), the Wilcoxon signed-rank test was used. A *p* value of <0.05 was considered statistically significant.

RESULTS

Baseline demographic characteristics of the patients and controls are summarized in Table 1. Of a total of 19 children with hemiplegic CP, the disease affected the right side and left side of the body in 9 and 10 patients, respectively. Of these patients, 11 were using solid AFOs and eight were using hinged AFOs, and the mean device wearing duration was 29.8±0.4 months. There was no significant difference between the duration of wearing of two types of AFO (p>0.05).

When the control and CP groups were compared, the PBS and FTSST scores were significantly higher in favor of the control group (p<0.001, p<0.001; Table 2). In the quantitative evaluation of dynamic balance with the device, the mean weight transfer time and sway velocity in the STS and the MVL parameter of the LOS test were significantly higher in the CP group (p<0.001, p<0.001, and p=0.017, respectively), while the mean MXE and DCL values were significantly higher in the control group (p=0.010 and p=0.001, respectively). There was no significant difference between the control and CP groups in any of the parameters of WA test (p>0.05) (Table 2).

When CP patients were assessed with and without AFO, a significant increase in PBS, a decrease in the FTSST duration, a reduction in sway velocity during STS test, and an increase in DCL parameters of LOS were observed in CP patients wearing AFOs (solid or hinged) (p=0.001, p=0.009, p=0.037, and p=0.044, respectively) (Table 3).

When the solid and hinged AFO groups were compared, there was no significant difference in the PBS, FTSST, and parameters measured with balance device (p>0.05) (Table 4).

TABLE 1
Baseline demographic characteristics of the study population

	Control Group			CP Group			
	n	%	Mean±SD	n	%	Mean±SD	*p**
Age (year)			10±1.6			9.5±2.2	0.359
Sex							0.118
Female	15	65.2		8	42.1		
Male	8	34.8		11	57.9		
BMI (kg/m^2)			18.3±3.2			20.1±3.1	0.060

SD: Standard deviation; BMI: Body mass index; CP: Cerebral palsy group; * Mann Whitney-U test.

TABLE 2
Functional and quantitative balance parameters

	Control Group		CP Group		
	Median	Min-Max	Median	Min-Max	*p**
PBS	56.0	56-56	52.5	49-56	<0.001
FTSST	7.3	4.2-9.2	9.4	0.7-11.7	<0.001
STS-WT	0.6	0.1-2.3	0.2	0.1-0.6	<0.001
STS-RI	23.7	13.7-59.3	28.8	19.7-80.7	0.079
STS-SV	2.7	1.2-5	5.2	4.0-7.1	<0.001
STS-DCL	12.6	-3.6-42.33	16.0	-25.66-55	0.553
WA-SW	15.0	1.8-23.1	10.6	0.13-23.0	0.300
WA-SL	56.3	39.6-82.1	55.3	11.7-97.5	0.553
WA-SP	92.0	58.8-132.4	77.0	52.6-316.13	0.098
LOS-RT	1.1	0.6-1.6	0.9	0.6-1.4	0.197
LOS-MVL	0.9	3.3-7.2	6.1	2.4-8.3	0.017
LOS-EPE	78.4	50.3-97.8	75.6	42.8-88.3	0.903
LOS-MXE	100.3	74.5-106.9	89.7	76.9-101.6	0.010
LOS-DCL	71.4	45.5-86.0	59.9	38.6-72.3	0.001

CP: Cerebral palsy; PBS: Pediatric Balance Scale; FTSST: Five times sit to stand test; STS: Sit to stand test; WT: Weight transfer time; RI: Rising index; SV: Sway velocity; DCL: Directional control; WA: Walk across test; SV: Step width; SL: Step length; SP: Speed; LOS: Limits of stability; RT: Reaction time; MVL: Movement velocity; EPE: End-point excursion; MXE: Maximum excursion; * Mann Whitney-U test.

TABLE 3
Balance parameters between barefoot and with AFO in patients with CP

	Barefoot		With AFO		
	Median	Min-Max	Median	Min-Max	*p**
PBS	52	43-56	55	51-56	**0.001**
FTSST	9.5	0.7-11.7	8.2	0.7-10.7	**0.009**
STS-WT	0.2	0.1-0.6	0.2	0.1-1.6	0.501
STS-RI	28.7	19.7-80.7	26	11.3-38.3	0.193
STS-SV	5.2	4.0-7.1	4.9	1.8-6.6	**0.037**
STS-DC	17.0	-25.7-55	9.7	-62.7-30.3	0.076
WA-SW	10.5	0.1-23	11.6	2.3-24.2	0.394
WA-SL	54.1	11.7-97.5	49.4	33.4-65.8	0.193
WA-SP	76.4	52.6-316.1	81.8	47.2-130.4	0.586
LOS-RT	0.9	0.6-1.4	0.8	0.4-1.5	0.587
LOS-MVL	6.2	2.4-8.3	4.9	3.6-8.4	0.133
LOS-EPE	76	52.8-88.3	70.5	55.8-94.4	0.698
LOS-MXE	90.8	76.9-101.6	97.8	79.1-107.6	0.205
LOS-DCL	60.9	38.6-72.3	67.4	58.3-74.6	**0.044**

CP: Cerebral palsy; PBS: Pediatric Balance Scale; FTSST: Five times sit to stand test; STS: Sit to stand test; WT: Weight transfer time; RI: Rising index; SV: Sway velocity; DC: Directional control; WA: Walk across test; SV: Step width; SL: Step length; SP: Speed; LOS: Limits of stability; RT: Reaction time; MVL: Movement velocity; EPE: End-point excursion; MXE: Maximum excursion; DCL: Directional control; * Mann Whitney-U test.

TABLE 4
Balance parameters between solid and hinged AFOs in patients with CP

	Solid AFO (n=11)		Hinged AFO (n=8)		
	Median	Min-Max	Median	Min-Max	*p**
PBS	55	51-56	55.5	54.0-56.0	0.418
FTSST	8.3	0.7-9.2	7.8	6.8-10.7	0.501
STS-WT	0.2	0.1-1.6	0.2	0.1-1.0	0.267
STS-RI	25.0	18.3-38.3	26.3	11.3-38.3	0.923
STS-SV	5.2	2.1-6.6	4.1	1.8-5.1	0.054
STS-DC	10.7	-22.0-30.3	8.7	-62.6-25.7	0.962
WA-SW	11.6	2.3-24.2	12.2	8.5-18.2	0.847
WA-SL	49.4	39.0-65.8	47.9	33.4-55.4	0.290
WA-SP	79.6	47.2-92.7	84.4	54.1-130.4	0.248
LOS-RT	0.8	0.4-1.5	0.9	0.6-1.3	0.700
LOS-MVL	4.8	4.1-6.6	5.5	3.6-8.4	0.665
LOS-EPE	70.5	59.3-94.4	72.4	55.8-90.4	0.773
LOS-MXE	97.8	87.0-105.9	96.3	79.1-107.6	0.773
LOS-DCL	67.3	48.3-71.0	69.8	52.9-74.6	0.211

CP: Cerebral palsy; PBS: Pediatric Balance Scale; FTSST: Five times sit to stand test; STS: Sit to stand test; WT: Weight transfer time; RI: Rising index; SV: Sway velocity; DC: Directional control; WA: Walk across test; SV: Step width; SL: Step length; SP: Speed; LOS: Limits of stability; RT: Reaction time; MVL: Movement velocity; EPE: End-point excursion; MXE: Maximum excursion; DCL: Directional control; * Mann Whitney-U test.

DISCUSSION

In this study, we examined the balance of children with hemiplegic CP with AFO functionally and quantitatively. Functionally balance was tested with PBS and FTSST, while quantitative balance was evaluated through the device-assisted STS, WA, and LOS tests.

Standing up as in the STS test is one of the frequent activities in daily life. The duration of the weight transfer during the STS test depends on the patient's standing after the foot has reached full contact, and may cause the patient to stand up at faster, compared to the control, if the patient has a good plantar flexing capacity. In a study conducted by Kenis-Coskun et al.,[21] the increase in the weight transfer of hemiplegic CP group was found to be contradictory to our results, which can be attributed to the inclusion of individuals with only GMFSC Level 1-2 and independent mobilizers without significant spasticity in the lower extremities in our study group. The STS test requires adequate leg strength and joint motion and, unless there is a serious defect in the patient group, it can be considered normal that no significant difference is observed in either group. On the other hand, the increase in the rate of sway velocity in the CP group indicates a decrease in balance, and a distortion of stability.[12] Moreover, there was a marked slowness in the CP group in the FTSST, which required more strength and durability than the STS test. Slowing in the FTSST may be a mechanism chosen to prevent disequilibrium or falls in children with CP. Based on these results, it can be assumed that the CP group can move quickly, but cannot keep up and cannot maintain their balance.

In the LOS test, voluntary control of body movements is investigated and lower extremity strength, coordination, and timing are examined. It is an assistive method used to calculate the risk of falling in diseases with mobility impairment.[22] Compared to the control group, the decrease in the MXE and DCL results of the CP group is probably due to the difficulty to reach the target, as malfunction in the motor control is present. In the CP group, the movement velocity was higher than the control group. Similar to the shorter weight transfer time in the STS in CP, this result indicates that patients with CP are able to move quickly toward a single goal; however, a high postural sway in doing so indicates that they cannot maintain their balance correctly.

Walking is one of the most basic physical activities and can be affected by many disorders. Although the WA test is sensitive in determining functional ability, it does not have enough specificity. In this study, there was no significant difference in the step width, step length, and speed during normal gait. This may be due to the fact that it was a short distance to walk and that all participants were instructed to walk at the fastest speed they could.

With orthosis, performance improvement on FTSST and a significant increase in PBS scores were detected in the CP group. In a study conducted by Wang et al.,[20] no significant benefit was observed on the BBS of short (<6 months) or long (>12 months) AFO wearing in stroke patients, while the median BBS score in both groups was found to be 51 (out of 56), indicating that there was no significant disruption in balance. In another study, the positive effect of AFO on balance was noted.[20,23] The fact that balance maintenance is easier with the use of AFO has been shown quantitatively by the increase in the DCL parameters of the LOS test and the reduction of postural sway in the STS test in addition to the functional balance tests. In studies in which the effects of AFOs on gait of CP groups were investigated, the step length and walking speed were found to increase, and cadence decreased.[24] In addition, it has been shown that spastic hemiplegic children develop walking symmetry with the use of AFO, thereby, reducing joint and body sway to a minimum.[25]

In a study of the effect of AFO use on balance in healthy populations, EPE and MXE were significantly reduced by orthosis use and it was found that AFO wear for the healthy population might be destabilizing.[12] In our study, compared to the healthy population, the use of AFO in the CP group facilitated movement control with improved balance. These findings suggest that, in addition to some study results showing that AFO has a contribution to the mobility and gait of patients with hemiplegic CP,[25,26] it also contributes positively to balance.

In the intra-group analysis, we observed no significant difference in the balance evaluation of hinged and solid AFO patients. The most likely reason for this may be the low number of patients evaluated.

Nonetheless, this study has several limitations. First, it has a relatively small sample size which may mask significant differences between the two groups. Second, the kinematic analysis was not performed. On the other hand, the results of this study are valuable, since it is one of the first studies to investigate the effect of AFO use on functional and quantitative dynamic balance tests in pure hemiplegic CP patients with GMFSC Level 1-2. It is also important that AFO shows the contribution to balance in children with mobilized hemiplegic CP, highlighting that the orthosis is not neglected at low GMFCS levels.

In conclusion, the AFO use offers a significant contribution to the functional balance in CP. Prescribing AFOs are usually required in ambulatory CP patients in combined with a well-designed standard physiotherapy. Nevertheless, there is still a need for further large-scale, long-term, treatment programmed studies to investigate the balance change of CP patients and the factors which may affect CP patients, which can also differentiate between solid and hinged AFOs and the timing of preferences of these orthoses.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding

The authors received no financial support for the research and/or authorship of this article.

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